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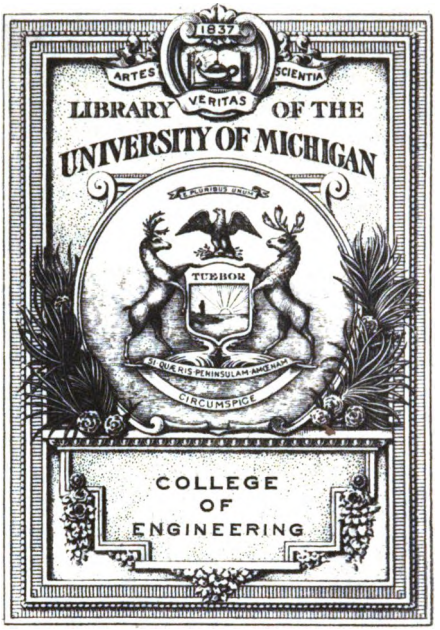

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MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. XLVIII.

SESSION 1876-77.—PART II.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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CONTENTS.

SECT. I.—MINUTES OF PROCEEDINGS.

PAGE

January 16 *and* 23, 1877.

Election of Members and Associates 1
Transfer of Associates to class of Members 1
Admission of Students 1
"The Repairs and Renewals of Locomotives." By A. McDONNELL. (1 plate, 1 woodcut) 2
Appendices: Tables of Repairs and Renewals per train mile on various English and foreign railways 16
Discussion on the Repairs and Renewals of Locomotives (1 plate) . . . 35
Action of Sea-water on Copper Sheathing 74

January 30, 1877.

"On the Combustion of Refuse Vegetable Substances, such as Straw, Reeds, Cotton Stalks, Brushwood, Megass, &c., under Steam Boilers." By J. HEAD. (2 plates) 75
Discussion on ditto (1 plate) 92
Excavating Apparatus 103

February 6, 13, 20 *and* 27, 1877.

Election of Honorary Member, Members, and Associates 104
Transfer of Associates to class of Members 104
Admission of Students 104
"The Sewage Question." By C. N. BAZALGETTE 105
Discussion on ditto (2 plates, 2 woodcuts) 160

March 6, 1877.

Election of Members and Associates 251
Transfer of Associates to class of Members 251
Admission of Students 251

Digitized by Google

SECT. II.—OTHER SELECTED PAPERS.

PAGE

"Canadian Narrow-gauge Railways." By E. WRAGGE 252

"Experiments and Observations on the Emission of Heat by Hot-water Pipes." By W. ANDERSON. (1 plate) 257

Memoirs of Deceased Members 266

Osborne Cadwallader Edwards, 266; Christopher Bagot Lane, 266; Thomas Talbot Bury, 269; Robert Wood Everett Green, 270; Thomas Tenison Ryan, 272.

SECT. III.—ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Construction and Working of the St. Gothard Railway. G. PACHO . . . 274

Consolidation Works on the Calabrian Railway. S. BILIA 277

Prussian Railways in 1875 280

Italian Railways in 1875. Prof. Dr. STÜRMER 282

Sorting Sidings for Marshalling Goods Trains. J. MICHEL 285

Length of Bessemer Steel Rails. H. WERNICH 288

Development of Rail Production in Russia 291

Carriage Traverser worked by Endless Rope. P. LEONHARDI 292

Tidal Harbour Improvement at Wilmington, Cal. C. B. SEARS 293

Repairing Slip at Palermo. W. THEIS 297

Accident to a Caisson at Rotterdam. D. A. W. KONING 299

Improvement of the Aar. J. ZÜRCHER 302

Regulation of the Danube at Vienna. I. LEDERER 304

Regulation of the North Elbe. H. DALMANN 307

On the Blasting of Ice 310

The Mérienne Dam on the Charente. M. ALEXANDRE 311

The Gileppe Dam. MM. BODSON, DETIENNE, and LECLERCQ. 312

Rhone Irrigation Canal. F. VIDALIN 315

Reservoirs of the Rio Rimac, Peru 318

Irrigation Duty of Water. J. S. BERESFORD 319

Hydraulic Experiments at Roorkee, 1875–76. Capt. A. CUNNINGHAM, R.E. 322

Laying of Subaqueous Mains across the Danube and the Regen. A. THIEME 322

The Brussels Gas Works. P. JULIEN 324

Gasholder of the Berlin Gas Works. W. SCHWEDLER 326

Lighting of Trains by Gas in the Mont Cenis Tunnel. 328

On the Influence of Pressure on Flames. Prof. Dr. V. WARTHA . . . 329

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PAGE

Mechanical Separation of Matters in Suspension in Gas or Vapours. F. Le Blanc 331

Application of the Mechanical Theory of Heat to the Study of Volatile Liquids. R. Pictet. 332

Condensation and Re-evaporation of Steam. J. Illeck 336

Manometer for High Pressures. L. Cailletet 340

Efficiency of Steam Vacuum Pumps. J. F. Flagg 340

Underground Pumping Engine at Fohnsdorf. B. Hess 341

On the Theory of the Centrifugal Pump. Prof. R. Escher 345

Atmospheric Hammers 346

Machinery for Crushing Sugar-cane. MM. Mignon and Rouart . . . 348

Production of Compressed Fuel from Earthy Lignite in Prussia. R. A. Schultz 349

Manufacture of White Forge Pig Iron from Luxemburg Ores. J. Wolters 352

Calorimetric Researches on the Carbides and Silicides of Iron and Manganese. MM. Troost and Hautefeuille 356

Disengagement of Ammonia in Rupture of Steel. M. Barré. 356

Influence of Temperature on Specific Heat of Mercury. A. Winkelmann . 357

Reduction of Silver Ores by the Californian Method in Mexico. H. Richter 358

Treatment of Argentiferous Zinc in North America. Dr. H. Wedding . 360

Recovery of Sulphur from Gypsum. Dr. O. Schott 362

Temperature of Explosion of Dynamite. P. Hess 363

Volatility of Nitroglycerine in Dynamite. P. Hess 364

Practical Method for Trial of Batteries. M. Leclanché 365

Electric Conductivity of Water and other inferior Conductors. H. Kohlrausch. 366

Application of Photography to Trigonometric Surveying 369

Armour-clad Turrets. Lieut. J. Kunka. 370

Index 375

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THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1876-77.—PART II.

SECT. I.—MINUTES OF PROCEEDINGS.

January 16, 1877.

GEORGE ROBERT STEPHENSON, President, in the Chair.

THE following Candidates were balloted for and duly elected:—CHARLES FREDERIC GREEN as Member; HENRY VERE BARCLAY, HENRY BLACKBOURN, WALTER HENRY COBLEY, Stud. Inst. C.E., JAMES GEORGE AYLWIN CREIGHTON, THOMAS HENRY EAGLES, M.A., WILLIAM THEODORE FOXLEE, Stud. Inst. C.E., ARTHUR STAPLES GERRARD, WILLIAM SCOTT HENDERSON, EDWIN JACKSON HUNT, WILLIAM STRONACH LOCKHART, Stud. Inst. C.E., GEORGE PHILLIPS MULOCK, Stud. Inst. C.E., COARD SQUAREY PAIN, WALLER SCOTT, WILLIAM ARCHIBALD SMITH, and ARTHUR JAMES HAMILTON SMYTHE, B.A., as Associates.

It was announced that the Council, acting under the provisions of Sect. iii., Cl. 7, of the Bye-Laws, had transferred CHARLES WILLIAM ARCHIBALD, GEORGE HUNTER TAIT, WILLIAM BARROW TURNER, HOWARD UNWIN, and ROBERT WINGATE from the class of Associate to that of Member.

Also that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. iv. of the Bye-Laws, as Students of the Institution:—EDWARD WILLIAM ANDERSON, HUGH ROBERT BLACKBURN, JOSEPH LESLIE COTTON, WILLIAM THOMAS DUNSDON, CHARLES GILL, EDWARD HAMILTON, FREDERICK JAMES HETHRINGTON, DANIEL MACALISTER, ROBERT FRANCIS PITT, THOMAS RAYNES, HUGH CECIL ROBINSON, HUBERT LE GAY SOLLY, THOMAS SUMMERS, HERBERT GEORGE SUMNER, FREDERICK HERBERT TULLOCH, JAMES WALLACE, Jun., ROBERT HENRY WILLIS, ARTHUR HENRY WILSON, and ALFRED WORTHAM.

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No. 1,469.—"The Repairs and Renewals of Locomotives."

By ALEXANDER MCDONNELL, M. Inst. C.E.[1]

THE expenditure required to maintain locomotives in efficient order varies according to the kind of traffic on the line, the age of the engines, the way in which the number of engines is increased by the addition of new ones on account of the growth of traffic, the state of the permanent way, and the nature of the curves and gradients of the line. Of all these the average age of the engines affects the cost of repairs most, so that on a railway, the traffic of which is rapidly increasing, the cost of repairs will generally be less than the average, unless the rate of increase in the number of engines is much less than that of the traffic receipts. The cost of repairs and renewals on nine railways from July 1868 to June 1876 is shown in Appendix I., and the increase in the number of engines and in the traffic receipts on six of these railways, from July 1868 to December 1875, in the following table (Plate 1):—

—	London and North Western.			Midland.		
	Dec. 1868.	Dec. 1875.	Increase per cent.	Dec. 1868.	Dec. 1875.	Increase per cent.
Number of engines	1,527	2,019	32·2	689	1,196	73·6
Train miles . .	11,461,870	16,329,406	42·4	7,248,104	11,724,269	61·7
	£.	£.		£.	£.	
Traffic receipts .	3,430,522	4,764,348	38·9	1,681,161	3,078,841	83·1
Receipts per train mile. . . .	s. d. 5 11·83	s. d. 5 10·02	..	s. d. 4 7·66	s. d. 5 3·02	..
	£.	£.		£.	£.	
Receipts per engine	2,246	2,360	5·0	2,440	2,574	5·5

—	Great Northern.			Great Western.		
Number of engines	493	533	8·1	867	1,223	42·2
Train miles . .	4,346,768	5,821,009	33·9	7,381,504	10,630,569	44·0
	£.	£.		£.	£.	
Traffic receipts .	1,136,882	1,514,300	33·2	2,024,366	2,918,546	44·2
Receipts per train mile. . . .	s. d. 5 2·77	s. d. 5 2·43	..	s. d. 5 5·82	s. d. 5 5·89	..
	£.	£.		£.	£.	
Receipts per engine	2,306	2,841	23·2	2,335	2,386	2·2

—	Lancashire and Yorkshire.			Great Southern and Western.		
Number of engines	455	670	47·2	120	138	15·0
Train miles . .	4,258,678	5,823,798	36·7	1,037,911	1,275,170	22·8
	£.	£.		£.	£.	
Traffic receipts .	1,274,285	1,841,403	44·5	273,148	382,351	40·0
Receipts per train mile. . . .	s. d. 5 11·81	s. d. 6 3·88	..	s. d. 5 3·16	s. d. 5 11·96	..
	£.	£.	decrease	£.	£.	
Receipts per engine	2,800	2,748	1·8	2,276	2,770	21·7

[1] The discussion upon this Paper occupied portions of two evenings.

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The average cost of repairs and renewals of engines during the above period is given for these six railways in the following table:—

COST of REPAIRS and RENEWALS from JULY 1868 to DECEMBER 1875.

——	Wages per Train Mile.	Materials per Train Mile.	Total.
	d.	*d.*	*d.*
London and North-Western	1·522	1·549	3·071
Midland	1·324	1·549	2·873
Great Northern	1·562	1·643	3·205
Great Western	1·932	1·288	3·220
Lancashire and Yorkshire	1·523	1·673	3·196
Great Southern and Western	1·539	1·912	3·451

Of these the Midland is the lowest; but on reference to the table it will be seen that the number of engines had increased 73·6 per cent. It does not therefore follow that the Midland railway was managed more economically than the Great Northern, on which the number of engines has been increased only 8·1 per cent., while the traffic receipts have increased 33·2 per cent. So large an addition of new engines, although it appears to have been justified by the augmentation of the traffic receipts, must make a considerable difference in the cost of repairs; and possibly the expenditure on the Great Northern may have been more economical than that of the Midland, on which line the cost of repairs will probably increase. The expenditure on the Great Western for wages, nearly 2*d.* per train mile, is much higher than on the other lines, on which it only amounts to a fraction over 1½*d.*, and the Author is unable to find any explanation for it, as the increase appears too large to be due to any difference in the form of accounts.

The receipts per train mile being high and the receipts per engine low on the London and North-Western show that that Company has a greater number of engines compared with the work to be done than the Great Northern, where the receipts per train mile are low and per engine relatively high. There has been a large addition to the number of engines on the Lancashire and Yorkshire; still the cost of repairs is as high as on other lines, on which the engines are reputed to be kept in more efficient order.

Even at the risk of entering too much into the statistics of a single railway, the Author thinks that the most trustworthy information as to the repairs and renewals of engines can be given by

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a careful examination of the result of rebuilding the locomotives on the Great Southern and Western railway of Ireland, with which he has been connected for several years. There is nothing exceptional in the position of this railway, in the miles run per engine, in the receipts per engine, or in the receipts per mile. The steepest gradients worked over are 1 in 128 on the main line, and 1 in 100 on the branch lines, exclusive of the gradients of 1 in 80 and 1 in 60 at Dublin and at Cork, up which the trains are "banked." The number of engines is smaller than on the principal English railways, so that an analysis of the expenditure is not so difficult. During the period from 1868 to 1875 the cost of repairs and renewals was in excess of the average, on account of the expenditure having been too low in previous years, and because the carriage makes the cost of materials slightly in excess of the average in England. In the discussion on a Paper by Mr. R. Price Williams, on "The Maintenance and Renewal of Railway Rolling Stock,"[1] Mr. Bramwell remarked, that if the different parts of an engine were renewed as they should be, an engine would have no termination to its life: "it would, in fact, go on,—a new blade and a new handle, and a new handle and a new blade,— so as to keep in existence perpetually." No doubt, if all the engines on a railway were of a good standard type, this should take place, and it would then be difficult to draw the line between repairs and renewals. In the present instance there is no difficulty in distinguishing repairs from renewals, because the new blade and the new handle were both required at the same time. In the year 1866 many of the engines were of an old and inferior design. None had received new boilers, although many of them were nearly twenty years old. The engines said to be rebuilt were entirely new, with the exception of a few wheels and frames taken from the old engines, and these were afterwards replaced by new ones, except in three engines.

When rebuilding was commenced, three types of engines were designed; and except that the first few engines were slightly modified to allow some of the wheels, &c., of the old engines to be used, these types have been carefully adhered to. Their general outlines and leading dimensions are shown in Plate 1.

The express passenger engine, Class 1, was designed for the mail and fast trains. The frames are inside, of solid plate, 1 inch thick. They are attached at one end to the cylinders, and at the other end to a cast-iron foot-plate, and are stayed by the motion-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxx., p. 136.

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plate and by a plate in front of the fire-box. The boiler is of ½-inch Lowmoor plate, 4 feet inside diameter. Each ring of the boiler is formed of a single plate; and the two sides and top of the outside fire-box casing are also formed of a single plate. The fire-box is of ½-inch copper, the tube-plate being ¾ inch thick, and the two sides and crown are formed of a single plate. There are one hundred and eighty-five tubes of brass. The cylinders are inside, and 17 inches in diameter, the length of stroke being 22 inches. The driving wheels are 6 feet 6 inches in diameter, and are coupled to the trailing wheels. The valve motion is of the ordinary kind, a screw being used for reversing. The coupling rods have cast-iron bushes, lined with white metal. The axle-boxes are of cast iron, and have the brasses cast into them. The hornblocks, of cast steel, are attached to the frame all round the opening for the axle-box; they have adjustable wedges for taking up the wear of the axle-boxes. The slide-blocks are of cast iron, and the little end steps are of wrought iron, case-hardened. The boiler is attached to the frames at the smoke-box end, is free to expand at the fire-box end, and does not touch the motion-plate. The heating surface consists of: tubes, 835 superficial feet; fire-box 96, and fire-grate 17½ superficial feet. The wheel base is, from the driving to the leading wheels 7 feet, and from the driving to the trailing wheels 7 feet 9 inches. The weight on the leading wheels is 10 tons, on the driving wheels it is 10·8 tons, and on the trailing wheels it is 9·5 tons, the total weight being thus 30·3 tons.

The performance of these engines for the year 1875 is given in the following table:—

Length of Journey.	Speed per Hour.	Average Load of Six-Wheel Carriages.	Maximum Load for Average of Whole Journey.	Maximum Load for Part of Journey.	Average Consumption of Coal per Engine Mile, 252,554 Miles.
Miles.	Miles.	Carriages.	Carriages.	Carriages.	lbs.
165½	38	8·03	11·54	14	25·64
„	38	7·64	10·54	13	
„	30	8·56	14·67	21	
„	30	8·59	14·47	16	

AVERAGE WEIGHT of CARRIAGES.

	Tons.	cwt.		Tons.	cwt.
1st class . . .	10	3	Composite . . .	8	10
2nd „ . . .	9	8	Post Office vans .	10	0
3rd „ . . .	9	10	Guards' vans . .	9	12

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The coal was from South Wales, of good quality, though much of it was small, being broken in shipment.

These engines have run an average distance of 48,748 miles in each interval between general repairs. The cost for repairs, exclusive of shop expenses and tools, to the end of 1875 was 0·986*d.* per mile. It is shown in detail in Appendix V., Table 1, Class 1.

The light passenger engine, Class 2, is of similar construction: the chief dimensions are:—Diameter of cylinders, 16 inches; length of stroke, 20 inches; diameter of the driving wheels, 5 feet 8 inches; the wheel base is, from the driving to the leading wheels 6 feet, and from the driving to the trailing wheels 7 feet 11 inches. The weight on the leading wheels is 9·2 tons, on the driving wheels it is 9·2 tons, and on the trailing wheels it is 8·8 tons, the total weight being thus 27·2 tons. The heating surface consists of: tubes, 774 superficial feet; fire-box 88½, and fire-grate 16 superficial feet. There are one hundred and seventy-five tubes.

The performance of these engines for the year 1875 is given in the following table:—

Length of Journey.	Speed per Hour.	Average Load of Six-Wheel Carriages.	Maximum Load for Average of Whole Journey.	Maximum Load for Part of Journey.	Average Consumption of Coal per Engine Mile. 644,412 Miles.
Miles.	Miles.	Carriages.	Carriages.	Carriages.	lbs.
165½	32	6·17	9·64	10	23·36
,,	30½	6·82	11·42	13	
,,	30½	4·93	7·64	10	
,,	32½	5·65	12·00	12	
,,	26½	7·00	11·55	18	
,,	28½	7·68	16·66	25	
,,	28¾	7·17	15·00	15	
,,	28	7·18	14·58	15	

These engines have run an average distance of 54,635 miles in each interval between general repair. The cost for repairs, exclusive of shop expenses and tools, to the end of 1875 was 0·809*d.* per mile. It is shown in detail in Appendix V., Table 1, Class 2.

The six-wheel coupled goods engine, Class 3, has already been described by Mr. Robinson in his Paper "On Modern Locomotives,"[1] and is in every respect similar to Class 1, as far as the general

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxvii., p. 7.

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construction. The leading dimensions are:—Diameter of cylinders, 17 inches; length of stroke, 24 inches; diameter of the wheels, 5 feet 1¼ inch; the wheel base is, from the driving to the leading wheels 7 feet 3 inches, and from the driving to the trailing wheels 8 feet 3 inches. The weight on the leading wheels is 10·9 tons, on the driving wheels it is 10·1 tons, and on the trailing wheels it is 9 tons, the total weight being thus 30 tons. The heating surface consists of: tubes, 855 superficial feet; fire-box 101½, and fire-grate 17½ superficial feet. There are one hundred and eighty-five tubes.

The performance of these engines for the year 1875 is given in the following table:—[1]

Length of Journey.	Time occupied in Running.		Time occupied at Stations.		Speed per Hour.	Average Load for Whole Journey.	Maximum Load.	Average Consumption of Coal per Engine Mile. 1,028,826 Miles.
Miles.	Hours.	Mins.	Hours.	Mins.	Miles.	Wagons.	Wagons.	lbs.
165½	9	22	3	26	17¾	31·5	50	
107	5	50	2	16	18¼	32·3	50	
107	5	40	3	46	19	24·8	51	
96½	5	25	3	52	17¾	29·9	49	
165½	8	37	3	8	19¼	27·7	52	37·6
107	5	40	4	56	19	30·8	54	
107	5	36	1	45	19	30·7	52	
96½	5	29	3	30	17½	27·5	52	

The wagons, which are nearly all covered, weigh from 4¾ to 5¼ tons, and carry 6 tons. The probable average load is from 3 to 4 tons.

These engines have run an average distance of 44,232 miles in each interval between general repair. The cost for repairs, exclusive of shop expenses and tools, to the end of 1875 was 0·9*d.* per mile. It is shown in detail in Appendix V., Table 1, Class 3. These engines are from one to eight years old; nine of them have run from 23,700 to 50,000 miles; seventeen from 50,000 to 100,000 miles, and twenty-three from 100,000 to 238,890 miles.

[1] Mr. Robinson stated in his Paper that this class of engine took an average load of fifty-five wagons, with an average consumption of coal of 35 lbs. per mile. This, however, was the maximum load at the time. The maximum load taken during the year 1875, and the average consumption of coal during the same period, is given in the table.

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In addition to these, tank engines (Plate 1) have been built for the branch lines. They have a bogie at the trailing end, on which the tank is carried; the leading and driving wheels are coupled, and the engines have 15-inch cylinders; in other respects they are similar to Class 2.

The greatest possible care has been taken to secure perfect uniformity. The cost of the engines is kept under six headings, which for convenience are denoted by the first six letters of the alphabet:—

A. The boiler complete with tubes, but without fittings.
B. The smoke-box, foot-plate, cab, splashers, &c.
C. Wheels, axles, frames, tires, springs.
D. Cylinders and machinery.
E. Mountings, injectors, safety-valves, &c.
F. Painting, lagging, sheeting, &c.

The cost of one of each class of engine, divided under each of these headings, is given in Appendix V., Table 2. It depends to a great extent on the kind of materials employed, and the price of all materials used in locomotives has varied greatly during the last few years. Table 3 (Appendix V.) has therefore been prepared, giving the weight, cost, and cost per ton of all the materials used in each of the three engines taken as examples.

In the following analysis of the expenses of maintenance and renewal, train miles are used in all cases of general expenditure; but when particular classes of engines, &c., are compared, engine miles are taken. The mileage is made out in the following form:—

MILEAGE from 1ST JANUARY, 1866, to DECEMBER 1875.

	Ten Years ending December 1875.
Passenger trains	13,974,654
Goods „	8,435,044
Total train miles	22,409,698
Banking	1,083,552
Shunting	958,275
Ballasting	830,542
Empty	28,161
Engines running on other lines	228,741
Total engine miles	25,538,969

Out of a total of seventy-one goods engines, twelve are daily in steam, shunting and banking, and three are always ballasting. The shunting done at stations by train engines, during the time allowed by the time-table, is not included in the shunting mileage,

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although much is done in this way. Shunting in excess of the time allowed in the time-table is calculated at 6 miles an hour. None is effected by hydraulic power, and only an average of £953 was spent yearly for horse shunting in the above period. The time occupied in shunting and delays at stations, including the work done by both shunting and train engines, for a period of twelve months, has been, on an average, 7·95 minutes for each wagon attached to a train.

The cost of repairs and renewals from December 1859 to July 1876 is shown for each half-year on Plate 1. It has been impossible to separate the shop expenses and repairs of tools from general repairs of the engines before the year 1865. The whole expenditure is divided into repairs proper, renewals, repairs of tools, and shop expenses, and is given in pence per train mile. The average cost per train mile from January 1866 to December 1875 is as follows (credits for engine power, for ballasting, &c., being deducted):—

—	Wages.	Materials.	Total.
	d.	*d.*	*d.*
Repairs	0·895	0·693	1·588
Renewals	0·393	0·867	1·260
Repairs of tools and machinery . .	0·218	0·116	0·334
Shop expenses	0·161	0·144	0·305
Total	1·667	1·820	3·487

The total cost of renewals is given in Appendix V., Table 4, under the same six headings as were used in the examples of single engines, to which is added the cost per train mile run from January 1866 to December 1875.

The total cost of repairs for the same period is given in Appendix V., Table 5, under the same headings for materials, but for wages the division is simply into shop repairs and running-shed repairs.

The materials which form the most important part of renewals are those which as a general rule last longest, or have the longest life, as boiler plate, copper plate, wheels, frames, &c.; while the materials which are required for repairs have to be often renewed. The difference is clearly shown by the analysis of Tables 4 and

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5 of the cost of renewals and repairs, into the most important classes of material used. This is given in Appendix V., Tables 6 and 7.

A great change has taken place on account of the extensive use of steel in locomotives, especially for axles and tires. Not only has the cost of tires been considerably reduced, but the indirect advantages have been very great. The length of time an engine is kept out of the shops, or the miles run between two general repairs, have been greatly increased by the use of steel tires, although some things have tended to neutralise the advantage, more particularly, in the Author's opinion, the injudicious use of white metal. In the years 1860 and 1861 the average mileage of the engines between two general repairs in the shops was 18,806 miles, while in the years 1874 and 1875 the average run between shop repairs of all engines was 40,648 miles. To estimate the advantage of steel tires, the sixteen years and a half from January 1860 to June 1876 have been selected for comparison. In the first five years iron tires were almost exclusively used; in the second iron was replaced to a great extent by steel on the engines, but iron tires were continued on the tenders; in the next five years steel tires were almost entirely used on engines, and on tenders iron tires were replaced by steel; and in the last year and a half this was exclusively the case. Appendix V., Table 8, gives a summary of this with the cost per train mile.

There is considerable difficulty in obtaining reliable information of the exact mileage run by iron tires, so as to compare it with the mileage run by steel tires on the same or similar engines, because when iron tires were used engines had their wheels often changed without a careful record being kept. The Author thinks that there should be great care in accepting the mileage of tires and axles whenever spare wheels are kept, so that the engines may have their wheels changed, as even when the greatest care is taken it is almost impossible to avoid errors. An average mileage may be obtained approximately, however, by taking all the tires used by a class of engine, and the mileage of the whole. In this way iron tires 6 feet 6 inches in diameter, on single-wheel engines, with 11 tons on the driving wheels, are found to have run on an average 114,533 miles, and steel tires on the same engines have run on an average 196,648 miles. Iron tires on engines with driving wheels 4 feet 6 inches in diameter, with four wheels coupled, have run on an average 52,295 miles, and steel tires have run on the same engines 105,673 miles. This seems to be a small

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mileage, as steel tires on similar engines, with driving wheels 5 feet in diameter, have run 204,708 miles. The following table gives a few examples of the mileage of cast-steel tires:—

MILEAGE of STEEL TIRES to JUNE 1876.

Engines.	Diameter of Driving Wheels.	Number of Wheels Coupled.	Weight on Driving Wheels.	Engine Miles run.	Remarks.
	Ft. Inches.		Tons.		
7	6 6	4	10·8	From 167,320 to 262,698	All in use.
5	5 8	4	9·2	From 212,058 to 278,943	All in use.
2	5 8	4	9·2	From 218,006 to 234,229	Worn out.
10	5 0	6	10·1	From 166,533 to 209,847	All in use.

The Author regrets that he cannot supply the mileage of Bessemer steel tires, as generally when Bessemer steel tires were used the engines were old and broken up before the tires were completely worn out.

No reliable account of the average mileage obtained from iron crank axles can be given. Before the year 1865, when steel crank axles came into use, the account of crank axles was so carelessly kept, and the wheels of engines were so often changed without any note being made, that no trustworthy result can be obtained. Particular cases of the mileage of iron crank axles are given in the following table, showing in some instances a great mileage, but they cannot be considered as affording much information as to the average. All the engines have inside frames.

MILEAGE of IRON CRANK AXLES.

Diameter of Driving Wheels.	Number of Wheels Coupled.	Engine Miles run.
Feet. Inches.		
6 6	Uncoupled	334,458
6 6	,,	343,949
6 6	,,	326,265
6 6	,,	308,405
6 6	,,	281,729
4 6	Four	159,106
4 6	,,	161,218
4 6	,,	149,803
4 6	,,	205,690
4 6	,,	138,764
5 0	,,	140,659
5 0	,,	80,661
5 0	,,	151,820

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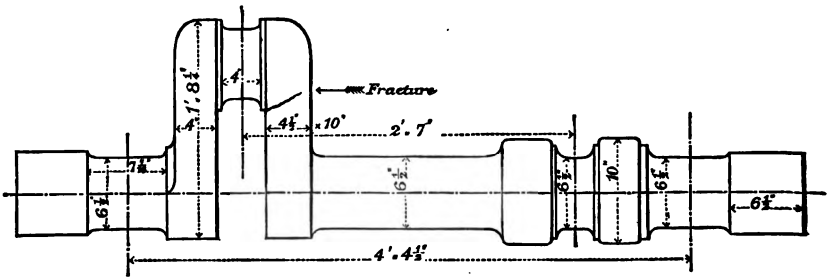
In 1865 steel crank axles were introduced. The result of the use of Bessemer steel crank axles is shown in the following table:—

MILEAGE of BESSEMER STEEL CRANK AXLES to 30TH JUNE, 1876.

Diameter of Driving Wheels.	Number of Wheels Coupled.	Engine Miles run.	Remarks.
Feet. Inches.			
5 8	4	150,835	These axles were changed, the engines having received new cylinders similar to standard.
5 8	4	92,453	
6 0	Uncoupled	51,760	Broken.
5 0	6	200,740	In use.
5 0	6	32,013	Broken.
5 0	6	213,204	In use.
5 0	6	30,142	Broken.
5 0	6	176,101	Broken.
5 0	6	152,386	In use.

In addition to these, ten Bessemer steel crank axles are in use, all made by one firm; two of them have run 230,507 and 278,943 miles, four have run from 191,990 to 209,847 miles, and four have run from 172,640 to 187,165 miles. Of cast-steel crank axles one hundred and twenty-one have been used, and one hundred and nineteen are still in use; one with a flaw broke through the middle after running 12,280 miles, and one broke after running 111,043 miles. The way the last-mentioned axle was turned and the position of the fracture are shown in the following sketch:—



The following table gives the mileage up to the 30th of June, 1876, of the one hundred and nineteen cast-steel crank axles now in use:—

Twenty-six axles have run	less than	. .	50,000	miles.
Thirty-eight "	"	from	50,000 to 100,000	"
Twenty-nine "	"	"	100,000 to 150,000	"
Nineteen "	"	"	150,000 to 200,000	"
Seven "	"	"	200,000 to 243,638	"

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Both iron and brass tubes have been employed.

Generally the water for the boilers has been good. During the ten years from 1866 to 1875 two thousand four hundred and thirty-three brass tubes[1] were used for repairs. The weight was 532 cwt., and the cost £2,386 12*s.* The average price was 9·6*d.* per lb., or 19*s.* 7*d.* each. The old tubes were sold for £736 9*s.* 5*d.*, the average price being 6*d.* per lb.

During the same time one thousand and ninety-two iron tubes were used, costing £508 11*s.* 11*d.*, or 9*s.* 3¾*d.* each on an average. The total cost of tubes both for repairs and renewals was—

Brass tubes for repairs . . .	£2,386	12	0			
Credit old tubes	736	9	5			
				£1,650	2	7
Iron tubes for repairs	508	11	11			
Credit second-hand tubes . . .	41	3	11			
				467	8	0
Brass tubes for renewals . . .	9,108	12	4			
Iron „ „ . . .	202	14	6			
				9,311	6	10
				£11,428	17	5

The average mileage of a number of complete sets of iron and brass tubes is given in the following table. The iron tubes were worn out, but the brass tubes are still in use:—

—	Total Miles.	Average Miles per Engine.	Remarks.
Twenty engines with iron tubes. .	3,338,746	166,937	Taken out.
Six passenger „ brass „ .	2,621,782	436,964	In use.
Fourteen goods „ „ „ .	4,066,114	290,437	In use.

The rate of wages of the men employed in locomotive shops has increased of late years, but generally the expenditure for labour for the repair and building of locomotives has not increased, on account of the more extensive use of machinery. From the year 1860 to 1875 the rate for smiths, turners, and boilersmiths increased from 8 to 12 per cent.; that for labourers increased from 17 to 22 per cent. The rate of wages for fitters

[1] Of this number, twelve hundred and thirty-one tubes, costing £1,192 9*s.*, were for the engines belonging to a line which became part of the Great Southern and Western by amalgamation; so that the value of brass tubes required for the repairs of all the engines except these was £1,194 3*s.*

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did not increase from 1860 to 1875; probably the rate in 1860, and for several years after, was above the mean on other lines of railway. The average rate of wages estimated from one fortnight in each year is given in the following table:—

AVERAGE RATE of WAGES per DAY.

Year.	Class of Artisan.							
	Fitters.	Turners.	Machine-men.	Fitters' Labourers.	Boiler-smiths.	Boiler-smiths' Labourers.	Smiths.	Smiths' Strikers.
	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.
1860	5 2¼	4 9½	2 10	1 11½	5 0	2 6	4 9½	2 3½
1861	5 0¾	4 10½	2 9	1 10¾	5 1	2 5	4 11½	2 3¼
1862	5 2	5 0	2 9	1 11½	5 1	2 5	4 10	2 5
1863	5 1	5 0½	2 11	1 11	5 1	2 4½	4 9	2 4½
1864	5 1¾	5 1¾	2 10¾	2 0	5 0½	2 5	4 10	2 5½
1865	5 0¾	5 2½	3 0	2 0½	5 2	2 6	5 1	2 5½
1866	5 0¾	5 2¾	3 1½	2 0½	5 2	2 6½	5 1	2 4¾
1867	5 2	5 0¼	2 9½	2 2½	5 0½	2 6½	5 0	2 5½
1868	5 2	5 2½	2 11	2 3¼	5 3	2 6½	5 0¾	2 6¾
1869	5 0½	5 2½	2 6½	2 1	5 1½	2 6	5 1½	2 6½
1870	5 0½	5 2½	2 7½	2 3¾	5 2	2 7½	4 10¾	2 7¾
1871	5 0¼	5 2½	2 6½	2 3¾	5 2½	2 8	5 0	2 7½
1872	5 3	5 4½	3 1	2 5¼	5 5½	2 8	5 2	2 8¼
1873	5 2¼	4 9¾	3 2	2 6½	5 5	2 11	5 2	2 8
1874	5 3	5 5½	3 2½	2 6½	5 6½	2 10	5 2	2 8
1875	5 1¾	5 3¾	3 0	2 4¾	5 7	2 11	5 2	2 7½

The following table gives the average working time and the rate of wages per day of nine hours for the half-years ending the 30th of June, 1872, and the 30th of June, 1875, apprentices being included with each class of workman:—

—	1872.			1875.		
	Time worked per Week.	Wages per Week.	Wages per Day, 9 hours.	Time worked per Week.	Wages per Week.	Wages per Day, 9 hours.
	Days. Hrs.	s. d.	s. d.	Days. Hrs.	s. d.	s. d.
Fitters and apprentices	5 3½	19 11¼	3 8½	5 3½	21 1	3 11
Turners and do.. .	5 3½	20 11	3 10½	5 2¾	23 2	4 4½
Fitters' labourers .	5 8½	14 4½	2 5	5 7½	15 2	2 7¼
Boilersmiths and apprentices	5 4¾	20 5½	3 8½	5 4¼	21 8	3 11½
Smiths	5 6¾	24 11	4 4	5 6¾	26 7	4 7½

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Appendix V., Table 10, gives in detail the materials used for repairs, the engines being divided into different classes. The age of the engines of each class is found by the average miles run from the time they commenced running to the 30th of December, 1875. A summary of this is supplied in Appendix V., Table 9. The cost of the repairs of locomotives on several foreign railways is also given in Appendices II. to IV. A comparison with foreign lines is often difficult, because the accounts are not made up exactly in the same way, and it is not known how far renewals are included in the published accounts.

The Author has carefully excluded everything from the tables which did not seem perfectly trustworthy and accurate. He takes this opportunity of thanking M. Forquenot, the chief Locomotive Engineer of the Paris and Orleans railway, for his great kindness in giving the cost of repairs and renewals on that line in a form similar to that used in this communication; also the cost of building one of his standard engines in detail. These tables are given in Appendix III. He has also to thank Mr. Wootten, the Locomotive Engineer of the Philadelphia and Reading railroad, for the information in Appendix II.

The Paper is illustrated by a series of diagrams, from which Plate 1 and the woodcut have been compiled.

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APPENDICES.

I.—ENGLISH RAILWAYS.—Repairs and Renewals per Train Mile.

Railway.	Wages or Materials.	Half Year ending 1868. Dec.	1869. June.	1869. Dec.	1870. June.	1870. Dec.	1871. June.	1871. Dec.	1872. June.	1872. Dec.	1873. June.	1873. Dec.	1874. June.	1874. Dec.	1875. June.	1875. Dec.	1876. June.
		d.	d.	d.	d.	d.	d.	d.	d.	d.	d.	d.	d.	d.	d.	d.	d.
London and North-Western	Wages.	1·720	1·794	1·690	1·632	1·649	1·474	1·363	1·408	1·393	1·445	1·573	1·498	1·494	1·387	1·476	1·397
	Materials.	1·580	1·861	1·789	1·606	1·384	1·374	1·421	1·315	1·321	1·731	1·643	1·473	1·718	1·551	1·524	1·475
	Totals.	3·300	3·655	3·479	3·238	3·033	2·848	2·784	2·723	2·714	3·176	3·216	2·971	3·212	2·938	3·000	2·872
Midland . .	Wages.	1·336	1·374	1·340	1·305	1·259	1·213	1·175	1·199	1·335	1·313	1·293	1·393	1·372	1·459	1·454	1·536
	Materials.	2·126	1·274	2·101	1·440	1·427	1·012	1·128	1·287	1·311	1·391	1·723	1·684	1·775	1·744	1·801	1·786
	Totals.	3·462	2·648	3·441	2·745	2·686	2·225	2·303	2·486	2·646	2·704	3·016	3·077	3·147	3·203	3·255	3·322
Great Northern	Wages.	2·059	2·149	1·890	1·763	1·592	1·516	1·480	1·454	1·440	1·464	1·408	1·473	1·412	1·418	1·239	1·406
	Materials.	1·801	1·867	1·432	1·579	1·474	1·596	1·527	1·640	1·595	1·763	1·717	1·808	1·702	1·724	1·446	1·447
	Totals.	3·860	4·016	3·322	3·342	3·066	3·112	3·007	3·094	3·035	3·227	3·125	3·281	3·114	3·142	2·685	2·853
Great Western.	Wages.	1·995	1·825	2·089	1·924	1·967	2·041	1·919	1·800	1·753	1·922	1·860	1·761	1·926	2·005	2·022	2·035
	Materials.	1·747	1·445	1·351	1·232	1·361	1·143	1·195	1·262	1·095	1·260	1·130	1·207	1·286	1·269	1·329	1·294
	Totals.	3·742	3·270	3·440	3·156	3·328	3·184	3·114	3·062	2·848	3·182	2·990	2·968	3·212	3·274	3·351	3·329

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I.—English Railways (*continued*).—Repairs and Renewals per Train Mile.

Railway.	Wages or Materials.	Half Year ending 1868. Dec.	1869. June.	1869. Dec.	1870. June.	1870. Dec.	1871. June.	1871. Dec.	1872. June.	1872. Dec.	1873. June.	1873. Dec.	1874. June.	1874. Dec.	1875. June.	1875. Dec.	1876. June.
		d.	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*
Lancashire and Yorkshire .	Wages.	1·371	1·429	1·469	1·395	1·396	1·405	1·416	1·276	1·441	1·716	1·557	1·531	1·604	1·957	1·751	2·055
	Materials.	1·572	1·473	1·514	1·826	1·582	1·805	1·548	1·606	1·647	2·124	1·836	1·656	1·488	1·722	1·657	2·213
	Totals.	2·943	2·902	2·983	3·221	2·978	3·210	2·964	2·882	3·088	3·840	3·393	3·187	3·092	3·679	3·408	4·268
Great Southern and Western .	Wages.	1·709	1·707	1·706	1·812	1·901	1·599	1·401	1·366	1·499	1·329	1·429	1·414	1·527	1·385	1·419	1·335
	Materials.	2·095	1·812	1·916	1·796	1·985	1·835	2·250	1·854	1·944	1·830	1·968	1·737	2·006	1·758	1·906	1·674
	Totals.	3·804	3·519	3·622	3·608	3·886	3·434	3·651	3·220	3·443	3·159	3·397	3·151	3·533	3·143	3·325	3·009
North-Eastern .	Wages.	1·967	2·100	1·918	1·918	1·912	1·951	1·873	1·986	2·069	2·170	2·126	2·408	2·452	2·506	2·498	2·535
	Materials.	1·662	1·969	1·731	1·694	1·637	1·610	1·512	1·767	1·743	1·984	1·919	2·007	1·800	2·158	1·964	1·917
	Totals.	3·629	4·069	3·649	3·612	3·549	3·561	3·385	3·753	3·812	4·154	4·045	4·415	4·252	4·664	4·462	4·452
Great Eastern .	Wages.	1·261	1·274	1·301	1·273	1·160	1·248	1·459	1·488	1·551	1·747	1·624	1·608	1·668	1·602	1·762	1·817
	Materials.	0·546	0·747	0·870	0·759	0·935	0·860	1·091	1·077	1·017	1·211	1·183	1·207	1·080	1·262	1·375	0·911
	New Engines	2·067	0·653	1·227	0·681	1·237	0·524	1·227	0·493	0·969	0·459	0·797	0·312	0·401	0·277	0·018	0·101
	Totals.	3·874	2·674	3·398	2·713	3·332	2·632	3·777	3·058	3·537	3·417	3·604	3·127	3·149	3·141	3·155	2·829
London and South-Western	Wages.	1·322	1·280	1·303	1·248	1·169	1·235	1·224	1·115	1·182	1·221	1·237	1·432	1·395	1·364	1·408	1·579
	Materials.	2·245	2·187	2·050	2·092	1·875	1·954	1·759	1·349	1·302	1·561	1·541	1·585	1·727	1·267	1·560	1·608
	Totals.	3·567	3·467	3·353	3·340	3·044	3·189	2·983	2·464	2·484	2·782	2·778	3·017	3·122	2·631	2·968	3·187

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II.—AMERICAN RAILROADS.

TABLE 1.—PHILADELPHIA and READING RAILROAD (U.S.A.). LOCOMOTIVE REPAIRS and RENEWALS, TEN YEARS ENDING NOVEMBER 1875.

Year ending	Number of Locomotives.	Miles.	Pence per Mile.			Average Load of Coal carried in each Train. (Ton = 2,240 lbs.)
			Repairs.	Renewals.	Total.	
						Tons.
Nov. 30, 1866	267	4,261,336	5·035	1·925	6·960	471
,, 1867	268	4,356,385	4·833	0·301	5·134	458
,, 1868	269	4,500,135	4·567	0·337	4·904	449
,, 1869	297	5,159,301	3·642	1·364	5·006	467
,, 1870	309	5,100,175	3·727	1·697	5·424	474
,, 1871	343	6,543,138	2·783	0·849	3·632	512
,, 1872	377	7,248,778	2·825	1·102	3·927	521
,, 1873	400	8,351,682	2·571	0·514	3·085	512
,, 1874	405	8,119,077	2·515	0·786	3·301	523
,, 1875	410	7,690,534	2·313	0·588	2·901	553

For the purposes of the preceding statement the average value of the dollar in each year has been taken as follows:—

1866.	1867.	1868.	1869.	1870.	1871.	1872.	1873.	1874.	1875.
s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.
2 11⅜	2 11⅜	2 11½	3 1	3 7½	3 7⅜	3 8½	3 7½	3 8⅜	3 6⅜

TABLE 2.—WEIGHTS HAULED in PASSENGER, GOODS, and COAL TRAINS in 1875, with AVERAGE COAL CONSUMED and COST of REPAIRS.

Train.	Miles run.	Loads (reduced to Tons of 2,240 lbs.)			Anthracite Coal used.		Engine Repairs in Pence per Mile.
		Average Weight of through Train, excluding the Engine and Tender.	Weight carried, exclusive of Engine, Tender, and Vehicles.		Tons of 2,240 lbs.	Lbs. per Mile.	
			Average Load.	Average through Load.			
Passenger	93	105·4	..	..	2·4	57	2·10
Goods .	93	Not given	162·5	75·9	3·6	87	2·13
Coal . .	190	Empty 294·0 Full . 846·6	666·6	552·6	10·3	121	3·13

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PHILADELPHIA AND READING RAILROAD, U.S.A.

In reply to inquiries, the Author has received the following information, through the kindness of Mr. Gowen, the President, and Mr. Wootten, the Locomotive Engineer, of the above railroad :—

1st. "The mileage of engines which appears in the annual statement is made up by adding three (3) per cent. for shunting to the trip mileage when the engine is employed in hauling passenger, general merchandise, or coal trains; but when engines are employed in irregular service, such as ballasting, shunting, delivering material for construction or maintenance of road, hauling wood or other supplies for the use of the company, &c., the mileage is daily recorded by the conductor of the engine upon a sheet furnished for that purpose, and at the end of the month his report of the aggregate miles run is placed upon the record."

2nd. "The average mileage made by an iron fire-box, burning anthracite coal, is 42,000; of steel, with same fuel, 120,000 miles, and of copper, 45,000."

3rd. "A set of iron tubes will average 138,000 miles. Our experience with brass tubes when under test was so unsatisfactory, that their further use was abandoned."

4th. "A set of cast-steel tires 2¾ inches thick by 46 inches outside diameter, six wheels being coupled, the total weight on which is 51,000 lbs., will average 170,000 miles."

5th. "The annual cost of tires for all engines cannot be stated with correctness. Many of our engines were furnished with cast-iron tires having a chilled face, and the introduction of steel tires has been so gradual—covering a period of about seven years—that this question cannot be more satisfactorily answered than by stating that the cost for steel tires, per 1,000 miles run is $2·41 (=8*s.* 7*d.*), and for chilled tires $5·12 (=18*s.* 3*d.*) per 1,000 miles run."

6th. "The cost of a set of four cast-iron engine wheels 5 feet 6 inches diameter is $565 (=£100 12*s.* 10*d.*), each wheel weighing 1,540 lbs.; their life may be safely estimated—ordinary wear and tear alone considered—at 600,000 miles."

7th. "The cost of a chilled bogie-truck wheel is $18·65 (=£3 6*s.* 5*d.*), and its life averages 34,000 miles."

8th. "The cost of a standard passenger engine, having cylinders 17 inches by 22 inches, is $13,603 (=£2,423 0*s.* 8*d.*); and the cost of a standard freight engine, having cylinders 18 inches by 24 inches, is $11,436 (= £2,037 0*s.* 9*d.*), no allowance being made for use of shop machinery in either case."

9th. "Boilers made entirely of steel are not in use on the Philadelphia and Reading railroad."

III.—FRENCH RAILWAYS.

PARIS and ORLEANS RAILWAY COMPANY.—MATERIALS and WORKING.

"PARIS, 11*th Nov.*, 1876.

"SIR,—I have made out and send you herewith, according to your desire:

"1st. Account of the costs of repairs and renewals of the locomotives and tenders of the Orleans Company during the year 1875.

"2nd. Detailed account of the construction of the engines Nos. 566 to 571 built in 1875 in the workshops of the Company.

"These two documents have been made out as far as possible in the form of those that you have been kind enough to send me. To do this, some inquiries have

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been necessary, which have delayed my reply. If the subdivision of the expenses is not quite exact, it is at least sufficiently so to furnish a regular comparison.

"You will observe that our renewal expenses are markedly less than yours. This difference is principally due to the fact that our opened network has not ceased to increase, and that, in consequence, the old rolling stock bears but a slight proportion to the effective total; the cost of repairs has therefore been small, while the mileage, which serves as the divisor, is considerably increased. I have ascertained this cost by taking the average of the last ten years.

"The cost per ton of the engines 566 to 571 amounts to £58 7*s.* 9*d.*, exclusive of general charges. Owing to the present low price of materials, the engines we are now contracting for will be less costly.

"Accept, &c.,
"V. FORQUENOT,
"*L'Ingénieur en Chef du Matériel et de la Traction.*"

TABLE 1.—PARIS and ORLEANS RAILWAY. REPAIRS and RENEWALS of LOCOMOTIVES and TENDERS for the YEAR 1875.

—		Amount. £.	s.	d.	Total. £.	s.	d.	Per Mile. d.
	Wages.							
Repairs .	Locomotives	33,255	14	5	38,997	3	9	0·606
	Tenders	5,741	9	4				
Renewals .	Locomotives	4,880	19	11	5,501	10	1	0·085
	Tenders	620	10	2				
Maintenance	Tools, Machinery, workshop, Stationary engines	2,390	15	6	2,390	15	6	0·037
General workshop expenses .	Foremen	2,267	6	8	7,996	10	1	0·124
	Accountants	756	1	3				
	Draughtsmen	1,027	17	5				
	Sundry clerks	893	16	9				
	Various	3,051	8	0				
					54,885	19	5	0·852
	Materials.							
Repairs .	Locomotives	48,821	18	5	57,201	2	0	0·889
	Tenders	8,379	3	7				
Renewals .	Locomotives	12,811	6	2	14,439	19	7	0·224
	Tenders	1,628	13	5				
Maintenance of machinery and tools, general workshop expenses . .		3,012	1	7	3,012	1	7	0·047
					74,653	3	2	1·160
					129,539	2	7	2·012
		Train mileage = 15,450,344						

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SUMMARY.

——	Total Wages.			Total Materials.			Total.			Per Mile.		
										Wages.	Materials.	Total.
	£.	s.	d.	£.	s.	d.	£.	s.	d.	d.	d.	d.
Repairs of locomotives and tenders . . .	38,997	3	9	57,201	2	0	96,198	5	9	0·606	0·889	1·495
Renewals of locomotives and tenders . . .	5,501	10	1	14,439	19	7	19,941	9	8	0·085	0·224	0·309
Maintenance of machinery and tools. General workshop expenses . . .	10,387	5	7	3,012	1	7	13,399	7	2	0·161	0·047	0·208
	54,885	19	5	74,653	3	2	129,539	2	7	0·852	1·160	2·012

TABLE 2.—PARIS and ORLEANS RAILWAY. COST of ENGINES Nos. 566–571, with SIX WHEELS COUPLED. Weight = 34 tons 1 cwt. 2 qrs. 12 lbs.

Division.	Wages.			Materials.			Total.		
	£.	s.	d.	£.	s.	d.	£.	s.	d.
Boiler, fire-box, tubes, Tenbrinck heating tube, chimney, dome, stays, pipe mounting	164	12	10	702	1	7	866	14	5
Ash-pan, foot-plate, cab, sand-box, and its gearing	45	1	7	58	12	10	103	14	5
Wheels, axles, journals, frame plates, springs, axle-boxes	112	16	10	361	14	5	474	11	3
Mechanism, cylinders, connecting rods, pumps, reversing gearing, &c.	200	0	0	210	8	0	410	8	0
Cocks and safety-valves	17	14	5	43	8	9	61	3	2
Painting, brass sheathing	20	19	2	52	4	10	73	4	0
Totals . . .	561	4	10	1,428	10	5	1,989	15	3
Cost per ton for the finished engine	16	9	5	41	18	4	58	7	9
Plus general charges	..			..			9	16	0
							68	3	9

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TABLE 3.—PARIS and ORLEANS RAILWAY. COST of the CONSTRUCTION of ENGINES Nos. 566–571, with SIX WHEELS COUPLED.

Weight and Price of the Materials employed.

—	Gross			Credits.			Net			Net Cost per Ton.		
	Weight.			Cost.			Weight.			Cost.					
	Cwt.	qrs.	lbs.	£.	s.	d.	Cwt.	qrs.	lbs.	£.	s.	d.	Cwt.	qrs.	lbs.	£.	s.	d.	£.	s.	d.
Boiler plates, side plates, cabs.	157	2	13	194	0	0	7	2	5	1	16	9	150	0	8	192	3	3	25	12	2
Fine iron	67	3	13	82	10	5															
Wrought iron	71	2	0	68	16	0	56	1	3	14	16	0	94	3	5	150	11	2	31	15	4
Sheet iron	11	2	23	14	0	9															
Wrought wheels	75	2	3	113	16	0	3	0	5	0	17	7	72	1	26	112	18	5	31	3	2
Iron frame plates	54	0	26	41	13	7	20	1	24	5	16	10	33	3	2	35	16	9	21	4	9
Bolts, screws, rivets	27	2	0	32	0	0	..			..			27	2	0	32	0	0	23	5	5
Cast iron	100	2	15	70	9	7	6	0	12	0	12	10	94	2	3	69	16	9	14	15	6
Steel	13	3	0	21	4	0	0	3	26	0	4	10	12	3	2	20	19	2	32	16	8
Steel axles	26	3	18	33	19	2	2	1	12	0	12	0	24	2	6	33	7	2	27	3	6
Coupling pins (iron)	8	2	23	10	16	0	1	0	20	0	7	2	7	2	3	10	8	10	27	15	4
Steel tires	44	3	13	60	16	0	1	3	24	0	9	7	42	3	17	60	6	5	28	2	6
Brass tubes	56	0	24	320	11	3	..			..			56	0	24	320	11	3	114	1	0
Copper plates	24	1	14	121	18	5	2	0	3	8	6	5	22	1	11	113	12	0	101	12	6
Stays and copper rivets	5	3	16	29	8	0	..			..			5	3	16	29	8	0	99	15	8
Copper tubes	3	1	6	25	4	0	0	1	16	1	13	7	2	3	18	23	10	5	162	1	8
Bronze	14	3	9	84	11	3	1	1	16	5	2	5	13	1	21	79	8	10	118	6	3
Cocks	1	2	8	16	17	7	..			..			1	2	8	16	17	7	214	16	6
Boiler sheathing (brass) and various.	15	2	26	101	13	7	3	2	15	13	9	7	12	0	11	88	4	0	145	16	2
Bouvret injector	1	1	25	12	16	0	..			..			1	1	25	12	16	0	173	15	5
Tenbrinck heating tube	6	2	9	33	8	10	1	3	7	7	14	5	4	3	2	25	14	5	107	17	6
Total	790	3	4	1490	10	5	109	0	20	62	0	0	681	2	12	1428	10	5	41	18	4

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TABLE 4.—PARIS and ORLEANS RAILWAY.

Number of engines in 1875	828
Miles run by engines during 1875	17,141,934
Average miles per engine	20,703

COAL CONSUMED by ENGINES.

Year.	Price of Coal per "Tonne" (2,200 lbs.)	Coal consumed per Mile.		Cost of Coal per Engine Mile.
		Passenger and mixed.	Goods.	
	£. s. d.	lbs.	lbs.	d.
1859	1 9 9·6	21·625	32·757	4·092
1860	1 7 10·1	22·532	35·117	4·064
1861	1 5 2·0	21·660	37·506	3·723
1862	1 3 5·8	21·501	38·151	3·504
1863	1 0 6·9	22·656	41·610	3·263
1864	0 19 2·5	22·656	42·549	3·145
1865	0 17 1·3	22·646	43·966	2·915
1866	0 16 2·5	24·478	44·991	2·946
1867	0 16 4·2	24·719	45·015	2·906
1868	0 16 1·1	24·634	44·494	2·906
1869	0 15 2·2	25·821	46·266	2·850
1870	0 14 8·6	27·001	47·510	2·870
1871	0 14 6·9	27·267	53·939	2·937
1872	0 14 6·3	26·349	49·864	2·930
1873	0 16 2·2	25·725	47·298	3·106
1874	0 17 10·0	25·169	45·565	3·298
1875	0 18 7·1	26·048	46·876	3·593

AVERAGE NUMBER of CARRIAGES or WAGONS in a TRAIN.

Passenger or Goods.	Description of Vehicle.	Main Line.		Branch Lines.	
		Av. No.	Total Av.	Av. No.	Total Av.
Passenger trains .	Carriages	6·25		6·73	
	Vans, carriage-trucks, horse-boxes, post-office vans	4·44		3·06	
			10·69		9·79
Mixed trains . .	Carriages	6·39		4·78	
	Vans, carriage-trucks, horse-boxes, post-office vans	1·86		1·25	
	Goods wagons . . .	5·09		6·93	
			13·34		12·96
Goods trains . .	Loaded wagons . . .	33·50		21·44	
	Empty wagons . . .	8·53		6·34	
			42·03		27·78

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TABLE 5.—PARIS, LYONS, and MEDITERRANEAN RAILWAY. COST of REPAIRS and RENEWALS of ENGINES and TENDERS in PENCE per TRAIN MILE.

Item.	1865.	1866.	1867.	1868.	1869.	1870.	1871.	1872.	1873.	1874.
	d.	d.	d.	d.	d.	d.	d.	d.	d.	d.
Wages . . .	1·601	1·250	·909	·845	·820	·769	·958	·910	·942	·978
Materials . .	1·453	1·376	1·313	1·288	1·381	1·055	1·497	1·355	1·588	1·877
Shop expenses .	·516	·456	·528	·346	·368	·385	·471	·400	·507	·806
Total . .	3·570	3·082	2·750	2·479	2·569	2·209	2·926	2·665	3·037	3·661

The amounts published in the accounts of the Paris, Lyons, and Mediterranean Company as repairs of engines include the cleaning of the engines. In the above figures, cleaning engines has been deducted. It is uncertain whether renewals are included in the above table.

COST of REPAIRS of ENGINES WORKING DIFFERENT TRAINS in 1874 in PENCE per TRAIN MILE.

Item.	Express.	Ordinary Passenger.	Goods.	Ballasting.	Shunting.
	d.	d.	d.	d.	d.
Wages	·536	·692	·921	·831	·792
Materials	1·030	1·327	1·767	1·593	1·519
Shop expenses	·294	·530	·656	1·829	·431
Total	1·860	2·549	3·344	4·253	2·742

AVERAGE LOADS of TRAINS.

Description.	1865.	1866.	1867.	1868.	1869.	1870.	1871.	1872.	1873.	1874.
Carriages in passenger trains . .	9·919	11·370	11·918	11·188	11·351	11·351	11·351	11·065	11·150	11·421
Wagons in goods trains	48·322	47·246	46·458	45·440	43·947	43·947	43·947	40·660	40·153	42·538
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons	Tons.	Tons.	Tons.	Tons.
Average load of wagons .	4·044	4·291	4·227	4·169	4·346	4·346	4·346	4·842	4·492	4·272

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CONSUMPTION of COAL in LBS. per MILE.

Trains.	1865.	1866.	1867.	1868.	1869.	1870.	1871.	1872.	1873.	1874.
Passenger .	30·233	31·112	32·959	32·760	33·947	36·683	40·093	36·644	38·034	35·156
Goods . . .	67·449	69·115	68·579	67·484	70·025	76·107	81·809	76·667	73·991	66·946

Average cost of coal per ton in 1874 . . 25*s*. 10·694*d*.
Number of engines in 1873 1,666
„ „ 1874 1,804

TABLE 6.—NORTHERN RAILWAY. COST of REPAIRS and RENEWALS of LOCOMOTIVES in PENCE per MILE. From JANUARY 1872 to DECEMBER 1874.

Item.	Half Year ending					
	1872.		1873.		1874.	
	June.	Dec.	June.	Dec.	June.	Dec.
	d.	*d.*	*d.*	*d.*	*d.*	*d.*
Repairs of engines . . .	2·279	2·234	2·211	2·410	2·476	2·596
„ „ wheels and tires	·189	·166	·041	·263	·283	·281
„ „ springs . . .	·026	·035	·039	·039	·035	·029
„ „ fire-bars . . .	·028	·022	·024	·051	·054	·052
„ „ tenders . . .	·239	·204	·200	·242	·248	·252
„ „ wheels and tires	·073	·066	·017	·115	·090	·087
„ „ springs . . .	·019	·015	·020	·023	·022	·020
Maintenance of tools and machinery	·020	·459	·189	·450	·081	·015
Totals . . .	2·873	3·201	2·741	3·593	3·289	3·332

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IV.—PRUSSIAN RAILWAYS.

COST of ENGINE REPAIRS, with AVERAGES per MILE of LINE and per TRAIN MILE RUN. YEAR 1874.

(Excerpt, "Statistische Nachrichten von den Preussischen Eisenbahnen.")

Railway.	Length of Line.	Train Miles run.	Cost of Engine Repairs.											
			Small Repairs.		Shop Repairs.				Credits[1] for Old Materials and Debits for Repair of Hired Engines.		Total.			
					Wages.		Materials.							
			Amount.	Per Mile.	Amount.	Per Mile.	Amount.	Per Mile.	—	Per Mile.	Amount.	Per Mile.	Average per Mile of Line.	Per Cent. of First Cost.
State Railways.	Miles.		£.	d.	£.	d.	£.	d.	£.	d.	£.	d.	£.	
1. Eastern	869·05	5,934,030	17,995·6	·728	25,564·6	1·034	37,688·3	1·524	10,767·7	·435	92,016·2	3·721	105·887	7·6
2. Lower Silesian and Berlin Junction .	368·91	4,993,058	4,173·2	·201	15,879·0	·763	34,016·6	1·635	9,563·2	·460	63,632·0	3·059	172·444	5·5
3 to 8. Sundry . . .	1,307·07	11,322,680	31,378·8	·665	61,074·2	1·295	84,754·0	1·796	19,293·9	·409	157,913·1	3·347	120·821	..
Total	2,545·03	22,249,768	53,547·6	·577	102,517·8	1·106	156,458·9	1·688	1,037·0	·011	313,561·3	3·382	123·207	6·5
Private Railways, partly under State control.														
2. Düsseldorf, Warburg, &c.	701·17	7,909,976	64,775·5	1·965	31,480·5	·955	53,558·5	1·625	7,020·7	·213	156,835·2	4·758	223·730	8·1
1 and 3. Sundry . .	807·65	5,287,880	8,579·7	·389	32,049·3	1·455	59,640·3	2·707	11,454·6	·520	88,814·7	4·031	109·974	..
Total	1,508·82	13,197,856	73,355·2	1·334	63,529·8	1·155	113,198·8	2·059	4,433·9	·081	245,649·9	4·467	162·790	7·5
Private Railways not under State control.														
22. Cologne and Minden	350·84	6,147,193	15,962·6	·623	21,515·6	·840	25,830·9	1·008	..	..	63,309·1	2·471	180·368	4·2
23. Rhine	515·58	5,105,886	20,429·9	·960	24,976·3	1·174	19,442·4	·914	14,337·0	·674	50,511·6	2·374	97·967	4·8
4, 5, 7, 8, 9, 10, 12 to 21, 24 to 29. . . .	3,338·45	19,271,641	65,767·9	·819	84,599·6	1·054	116,421·8	1·450	24,237·0	·302	242,552·3	3·021	72·655	..
Total	4,204·87	30,524,720	102,160·4	·803	131,091·5	1·031	161,695·1	1·271	38,574·0	·303	356,373·0	2·802	84·752	..
6 and 11 not analysed .	574·56	2,611,692							3,356·1	·308	42,758·0	3·929	74·414	..
Total	4,779·43	33,136,412							41,930·1	·304	399,131·0	2·891	83·511	5·5
Grand Total . .	8,833·28	68,584,036							45,327·0	·158	958,342·2	3·354	108·492	6·3

[1] Credits in antique figures.

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V.—GREAT SOUTHERN AND WESTERN RAILWAY OF IRELAND.

TABLE 1.—COST of REPAIRS of THREE STANDARD CLASSES of LOCOMOTIVES from JANUARY 1866 to DECEMBER 1875. (Exclusive of Shop Expenses, and Tools or Machinery.)

Description of Materials.	Class 1. 10 Mail Engines, 1,574,048 Miles.		Class 2. 20 Passenger Engines, 3,141,327 Miles.		Class 3. 49 Goods Engines, 5,100,013 Miles.	
	Amount.	Per Mile.	Amount.	Per Mile.	Amount.	Per Mile.
	£. s. d.	d.	£. s. d.	d.	£. s. d.	d.
Copper plates . .	147 6 6	·023	15 17 10	·001	367 13 7	·017
„ stays . .	38 11 3	·006	14 8 6	·001	131 6 6	·006
Fire-bars and brick arch	510 19 1	·078	609 12 11	·047	1,861 14 8	·088
Iron for smoke-box, foot-plate, &c. .	118 4 11	·018	119 3 3	·009	220 9 5	·010
Axles.	..	..	336 19 3	·026	440 10 10	·021
Tires	171 2 7	·026	414 2 7	·032	356 8 11	·017
Springs	632 2 6	·096	628 8 10	·048	1,423 10 2	·067
Axle-boxes . . .	264 16 10	·040	304 7 10	·023	600 8 10	·030
Axle-brasses . .	167 17 1	·025	256 0 11	·020	504 14 1	·023
Big-end brasses . .	23 17 8	·004	30 6 5	·002	81 10 8	·004
Cylinders and pistons	219 12 5	·034	485 7 10	·037	723 9 6	·034
Glands and bushes .	97 6 6	·015	140 6 9	·010	367 19 7	·017
Slide-valves . . .	119 14 4	·018	186 9 10	·014	307 3 6	·014
Eccentric liners . .	136 8 6	·021	192 14 3	·015	580 8 2	·027
Sundry white metal .	183 17 0	·028	264 16 9	·020	648 5 3	·030
Miscellaneous . .	752 1 8	·114	1,966 2 4	·150	2,215 11 10	·104
Totals . . .	3,583 18 10	·546	5,965 6 1	·455	10,831 5 6	·509
Credits . . .	680 19 4	·104	993 3 6	·076	2,157 2 4	·101
Net	2,902 19 6	·442	4,972 2 7	·379	8,674 3 2	·408
Wages . . .	3,565 11 3	·544	5,622 18 10	·430	10,511 14 3	·492
Totals . . .	6,468 10 9	·986	10,595 1 5	·809	19,185 17 5	·900

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TABLE 2.—COST of CONSTRUCTION of THREE STANDARD CLASSES of LOCOMOTIVES.

(Charges for Shop Expenses, Tools, or Machinery not included.)

Section.	Class 1. Mail Engines. Average Cost each.									Class 2. Ordinary Passenger Engines. Average Cost each.									Class 3. Heavy Goods Engines. Average Cost each.								
	Materials.			Wages.			Total.			Materials.			Wages.			Total.			Materials.			Wages.			Total.		
	£.	s.	d.	£.	s.	d.	£.	s.	d.	£.	s.	d.	£.	s.	d.	£.	s.	d.	£.	s.	d.	£.	s.	d.	£.	s.	d.
A Boiler . . .	435	14	0	93	15	0	529	9	0	406	3	7	111	1	0	517	4	7	535	17	3	108	16	7	644	13	10
B Smoke-box, &c.	71	10	10	94	11	8	166	2	6	80	17	10	75	1	9	155	19	7	83	5	10	75	6	6	158	12	4
C Wheels, frames, &c. . . .	532	10	9	84	14	7	617	5	4	458	12	0	72	2	6	530	14	6	534	10	3	64	14	11	599	5	2
D Machinery .	138	9	10	194	18	11	333	8	9	131	11	3	158	14	11	290	6	2	169	1	1	185	9	6	354	10	7
E Mountings .	112	9	4	35	9	2	147	18	6	86	5	7	29	11	7	115	17	2	89	8	5	32	1	5	121	9	10
F Painting, &c. .	46	5	3	30	4	2	76	9	5	42	9	5	15	9	10	57	19	3	42	2	5	22	6	4	64	8	9
Total . .	1,337	0	0	533	13	6	1,870	13	6	1,205	19	8	462	1	7	1,668	1	3	1,454	5	3	488	15	3	1,943	0	6

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TABLE 3.—WEIGHT, COST, and COST per TON, of MATERIALS used in the CONSTRUCTION of THREE STANDARD CLASSES of LOCOMOTIVES.

Materials.	Class 1.									Class 2.									Class 3.								
	Weight.			Cost.			Cost per Ton			Weight.			Cost.			Cost per Ton.			Weight.			Cost.			Cost per Ton.		
	Cwt.	qrs.	lbs.	£.	s.	d.	£.	s.	d.	Cwt.	qrs.	lbs.	£.	s.	d.	£.	s.	d.	Cwt.	qrs.	lbs.	£.	s.	d.	£.	s.	d.
Boiler plate	75	2	20	131	13	6	34	16	0	62	2	20	98	4	0	31	6	8	76	2	18	135	15	3	35	8	4
Yorkshire iron	9	0	7	9	18	5	21	17	10	4	0	24	4	13	3	22	2	6	6	0	19	7	10	4	24	7	4
Iron forgings	76	0	18	72	18	6	19	3	0	74	0	14	69	16	2	18	16	8	86	0	25½	84	17	9	19	13	9
Wheel „	68	3	17½	172	13	9	50	2	5	53	3	26	128	14	3	47	13	4	61	3	14	158	16	1	51	6	7
Frame plates	26	0	0	55	15	0	42	17	8	22	1	9	60	0	0	53	14	9	25	2	0	68	10	0	53	14	6
Staffordshire iron	119	0	27¼	64	12	10	10	17	5	94	0	13	76	7	10	16	4	8	89	0	12	67	12	6	15	3	6
Bolts, nuts, and rivets	21	1	1	32	18	10	31	0	0	20	0	25½	44	1	0	43	11	3	22	1	6	52	15	1	47	6	1
Iron castings	99	1	12	55	5	10	11	2	7	96	3	0	48	19	2	10	6	8	95	1	10¾	47	15	10	10	0	6
Steel	24	2	6	44	19	5	36	12	7	22	2	1	45	14	4	40	6	1	30	3	6¼	65	14	8	42	13	6
Steel axles	15	3	11	31	16	8	40	3	10	13	2	26	27	9	5	40	0	3	17	2	0	34	19	11	40	0	0
Steel crank axles	25	0	3	94	1	2	75	3	4	19	3	13	74	10	0	75	0	0	25	2	13	95	19	5	74	18	7
Steel tires	56	2	11	107	10	8	38	0	0	50	2	23	97	12	6	38	10	2	50	0	10	100	3	7	40	0	0
Brass tubes	37	2	27	132	1	11	70	0	0	27	1	12	137	4	10	100	6	8	36	0	15½	185	10	1	102	13	3
Copper plate	22	3	5	104	2	9	91	7	5	21	3	23	99	19	9	91	1	8	25	0	23	140	2	1	111	3	4
„ stays	5	3	25	29	19	4	100	2	7	5	0	9	30	1	11	118	4	10	5	1	18	26	6	9	97	7	0
„ tube	2	1	25½	18	19	1	152	14	5	1	3	22½	18	9	3	189	5	11	1	2	0¾	12	13	11	168	10	6
Brass castings	7	2	21¼	29	7	8	76	8	10	7	3	23	31	17	2	80	1	5	9	1	6¾	36	7	10	78	3	1
Injectors	1	1	0	54	0	0				1	3	10½	39	10	0				1	3	10½	39	10	0			
Finished brass and sundries	38	2	14	116	1	6				25	3	16½	96	16	11				33	3	5	113	6	1			
Totals	734	0	27½	1,358	16	10				627	1	3	1,230	1	9				700	1	18	1,474	7	2			
Credits	6	3	21	21	16	10				8	1	11	24	2	1				5	3	11½	20	1	11			
Net materials	727	1	6½	1,337	0	0				618	3	20	1,205	19	8				694	2	6½	1,454	5	3			
Wages				533	13	6							462	1	7							488	15	3			
Totals	727	1	6½	1,870	13	6				618	3	20	1,668	1	3				694	2	6½	1,943	0	6			

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TABLE 4.—ABSTRACT of the COST of ENGINES and TENDERS RENEWED from JANUARY 1866 to DECEMBER 1875.

(Not including unfinished Work, or Charges for Shop Expenses, Tools, &c.)

Section.	Materials.				Wages.				Total.			
	Amount.			Per Train Mile.	Amount.			Per Train Mile.	Amount.			Per Train Mile.
	£.	s.	d.	d.	£.	s.	d.	d.	£.	s.	d.	d.
A Boiler . . .	30,643	0	11	·328	6,332	7	3	·067	36,975	8	2	·395
B { Smoke-box, cab, &c. . . . }	4,277	16	9	·046	5,252	17	2	·056	9,530	13	11	·102
C { Wheels, frames, &c. . . . }	26,834	13	0	·287	5,505	17	0	·059	32,340	10	0	·346
D Machinery . .	8,917	13	2	·095	12,014	19	7	·129	20,932	12	9	·224
E Mountings . .	7,190	7	4	·077	2,416	6	5	·026	9,606	13	9	·103
F Painting, &c. .	2,696	8	4	·029	1,381	1	5	·015	4,077	9	9	·044
Total engines .	80,559	19	6	·862	32,903	8	10	·352	113,463	8	4	1·214
Tenders (including tanks, bogies, &c., for tank engines).	13,610	13	8	·146	4,563	8	10	·049	18,174	2	6	·195
Totals	94,170	13	2	1·008	37,466	17	8	·401	131,637	10	10	1·409
Credits (old engines and tenders broken up)	8,961	15	4	·096	..			..	8,961	15	4	·096
Net Totals	85,208	17	10	·912	37,466	17	8	·401	122,675	15	6	1·313
Average cost per engine for the 64 engines rebuilt . . .	1,258	15	0	..	514	2	4	..	1,772	17	4	..
Average cost per tender for the 38 tenders rebuilt . . .	298	12	7	..	103	6	8	..	401	19	3	..

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TABLE 5.—SUMMARY of the COST of ENGINE and TENDER REPAIRS from JANUARY 1866 to DECEMBER 1875.

(Including Ballast Engines and Engines lent to other Companies.)

	Section.	Amount. £. s. d.	Per Train Mile. d.
A	Boiler	13,544 17 2	·145
B	Smoke-box, cab, &c.	2,464 8 11	·026
C	Wheels, frames, &c.	24,184 4 6	·259
D	Machinery	23,490 15 3	·252
E	Mountings	5,528 10 4	·059
F	Painting, &c.	2,782 1 2	·030
	Total materials for engines	71,994 17 4	·771
	„ „ tenders	13,058 5 4	·140
	„ „ engine and tender	85,053 2 8	·911
	Credits	12,303 14 8	·132
	Net materials	72,749 8 5	·779
	Wages, shed repairs, engines	28,776 7 1	·308
	„ shop „ „	45,604 14 11	·488
	„ repairs of tenders	13,325 12 6	·143
	Total materials and wages	160,456 2 11	1·718

TABLE 6.—MATERIALS USED for RENEWAL of ENGINES from JANUARY 1866 to DECEMBER 1875.

Description of Materials.	Cost. £. s. d.	Per Train Mile. d.
Boiler plate	9,310 11 1	·100
Copper plate	7,581 7 8	·081
„ stays	1,537 18 1	·017
Tubes	9,311 6 10	·100
Wheels	7,662 19 6	·082
Axles	5,991 10 10	·064
Tires	5,990 3 4	·064
Frames	3,123 4 9	·033
Hornblocks	1,210 5 0	·013
Cylinders	2,687 17 0	·029
Injectors	2,838 1 2	·030
Sundries	23,314 14 3	·249
Total	80,559 19 6	·862

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TABLE 7.—MATERIALS USED for ENGINE REPAIRS from JANUARY 1866 to DECEMBER 1875.

Description of Materials.	Cost.	Per Train Mile.
	£. s. d.	d.
Copper plate and stays	3,337 19 9	·036
Boiler tubes	2,895 3 11	·031
Fire-bars and brick arch	6,018 12 2	·064
Axles	5,382 10 6	·057
Tires	9,236 12 1	·099
Springs	6,411 3 0	·068
Axle-boxes and brasses	6,068 17 2	·065
Cylinders, pistons, &c.	3,810 15 0	·041
Slide-valves, glands, and bushes	3,621 16 4	·039
Eccentric straps and liners	2,487 16 1	·027
Sundry other patent metal	3,716 13 6	·040
Miscellaneous	19,006 17 10	·204
Total	71,994 17 4	·771

TABLE 8.—COST of TIRES for REPAIRS and RENEWALS from JANUARY 1860 to JUNE 1876.

(The original thickness of the tires was 2¾ inches.)

Five Years 1860, 1861, 1862, 1863, 1864.

Class.	Iron.	Steel.	Total.	Per Train Mile.	Miles.
	£. s. d.	£. s. d.	£. s. d.	d.	
Passenger	3,646 7 2	47 1 5	3,693 8 7	·165	5,365,352
Goods	2,817 5 1	698 4 3	3,515 9 4	·287	2,938,028
Total engine	6,463 12 3	745 5 8	7,208 17 11	·208	8,303,380
Tender	4,099 10 2	..	4,099 10 2	·119	..
Total	10,563 2 5	745 5 8	11,308 8 1	·327	..

Average price of tires during this period. } Iron tires, engine, 38/4 per cwt. Steeled tires, engine, 44/6 per cwt.
„ „ tender, 33/3 „ „ „ tender, 42/0 „
Steel tires, engine, 72/0 per cwt.

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TABLE 8 (*continued*).

Five Years 1865, 1866, 1867, 1868, 1869.

Class.	Iron.	Steel.				Total.			Per Train Mile.	Miles.
		Repairs.			Renewals.					
	£. s. d.	£. s. d.			£. s. d.			£. s. d.		
Passenger . .	1,120 15 0	2,704 16 8			1,976 9 4			5,802 1 0	d. ·222	6,267,399
Goods . . .	866 7 2	1,668 16 8			1,074 8 6			3,609 12 4	·229	3,777,824
Total engine .	1,987 2 2	4,373 13 4			3,050 17 10			9,411 13 4	·224	10,045,223
Tender . . .	2,493 8 5	304 8 1			407 16 0			3,205 12 6	·077	..
Total . .	4,480 10 7	4,678 1 5			3,458 13 10			12,617 5 10	·301	..

Average price of tires during this period. Iron tires, engine, 36/3 per cwt. Steel tires, engine, 45/9 per cwt.
" " tender, 33/9 " " " tender, 30/4 "
Steeled tires, engine, 47/11 per cwt.

Five Years 1870, 1871, 1872, 1873, 1874.

Class.	Iron.	Steel.				Total.			Per Train Mile.	Miles.
		Repairs.			Renewals.					
	£. s. d.	£. s. d.			£. s. d.			£. s. d.		
Passenger . .	34 19 5	2,075 7 3			1,205 11 6			3,315 18 2	d. ·109	7,259,695
Goods . . .	64 4 2	2,443 5 10			1,584 1 10			4,091 11 10	·222	4,422,471
Total engine .	99 3 7	4,518 13 1			2,789 13 4			7,407 10 0	·152	11,682,166
Tender . . .	248 10 8	3,347 14 9			1,476 2 0			5,572 7 5	·114	..
Total . .	347 14 3	8,366 7 10			4,265 15 4			12,979 17 5	·266	..

Average price of tires during this period. Iron tires, engine, 24/7 per cwt. Steel tires, engine, 37/11 per cwt.
" " tender, 27/5 " " " tender, 33/7 "

One Year and a Half, January 1875 to June 1876.

Class.	Iron.	Steel.				Total.			Per Train Mile.	Miles.
		Repairs.			Renewals.					
		£. s. d.			£. s. d.			£. s. d.		
Passenger . .	..	96 4 4			148 6 4			244 10 8	d. ·025	2,340,736
Goods . . .	..	118 12 1			235 13 8			354 5 9	·062	1,368,940
Total engine .	..	214 16 5			384 0 0			598 16 5	·039	3,709,676
Tender . . .	..	657 11 11			259 7 0			916 18 11	·059	..
Total . .	..	872 8 4			643 7 0			1,515 15 4	·098	..

Average prices during this period. Steel tires, engine, 30/2 per cwt. Tender, 34/8 per cwt.

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TABLE 9.—SUMMARY of the COST of REPAIRING DIFFERENT CLASSES of LOCOMOTIVES from JANUARY 1866 to DECEMBER 1875.

Class of Engine.				Average Run per Engine during their Life.	Materials.				Wages.				Total.			
No.	Maker or Description.	Diameter of Driving Wheels.	How Coupled.		Amount.			Per Engine Mile.	Amount.			Per Engine Mile.	Amount.			Per Engine Mile.
	Passenger.	Feet.		Miles.	£.	s.	d.	d.	£.	s.	d.	d.	£.	s.	d.	d.
11	Sharp	5½	Single	465,471	1,736	3	4	·334	4,042	8	11	·776	5,778	12	3	1·110
20	Bury	6	,,	388,028	2,656	3	3	·391	4,686	16	8	·739	7,342	19	11	1·130
13	G. S. and W. Ry.	6½	,,	424,523	7,806	6	6	·575	8,624	1	0	·634	16,430	7	6	1·209
10	Standard 1.	6½	D. & T.	157,369	2,902	19	6	·412	3,565	11	3	·543	6,468	10	9	·985
20	,, 2.	5½	,,	157,066	4,972	2	7	·379	5,622	18	10	·429	10,595	1	5	·808
10	Bogie tank, Standard 2A	5½	,,	85,140	928	12	1	·262	2,038	11	6	·577	2,967	3	7	·839
10	C. and Yl. Ry. tank	Various.		239,947	6,740	14	4	·837	6,829	19	11	·847	13,570	14	3	1·684
	Goods.															
8	Bury	5	L. & D.	397,009	2,095	4	2	·561	3,689	18	2	·979	5,785	2	4	1·549
17	G. S. and W. Ry.	4½	,,	288,336	9,214	12	8	·617	12,949	4	10	·866	22,163	17	6	1·483
8	,, ,,	4½	L. D. T.	316,880	5,493	1	2	1·017	6,810	3	11	1·262	12,303	5	1	2·279
49	Standard 3	5	,,	103,818	8,674	3	2	·408	10,511	14	3	·494	19,185	17	5	·902
	Unclassed	..	..	340,701	6,471	0	4	..	5,009	12	9	..	11,480	13	1	..
	Total engines	..	..	243,440	59,691	3	1	·566	74,381	2	0	·704	134,072	5	1	1·270
	Tenders	..	..	..	13,058	5	4	·141	13,325	12	6	·143	26,383	17	10	·284
	Total	..	..	..	72,749	8	5	..	87,706	14	6	..	160,456	2	11	..

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49

Singled. 6 feet.		Six coupled. Standard 3. 5 feet.				Unclassed.				Total.					
3,256	Per Mile.	5,100,013½			Per Mile.	808,163¾			Per Mile.	25,318,381			Per Mile.	Per Engine Mile.	Per Train Mile.
424		103,818				340,701				243,440					
£.	d.	£.	s.	d.	d.	£.	s.	d.	d.	£.	s.	d.	d.	d.	d.
232	·037	367	13	7	·018	34	10	3		2,370	9	4		·023	·026
162	·038	131	6	6	·006	43	10	10		967	10	5		·009	·010
641	·085	42	7	9	·088	5	14	8		2,895	3	11		·028	·031
507	·082	1,861	14	8	·002	197	10	3		6,018	12	2		·057	·064
162	·020	189	13	2	·008	69	8	9		1,293	1	4		·012	·014
235	·040	319	9	8	·015	537	7	11		2,464	8	11		·023	·026
970	·107	440	10	10	·017	722	16	11		5,382	10	6		·051	·057
1,723	·172	356	8	11	·021	1,111	15	9		9,236	12	1		·087	·099
846	·090	1,423	10	2	·067	306	6	11		6,411	3	0		·061	·069
103	·060	327	15	11	·015	1,329	13	5		3,153	18	11		·030	·034
323	·039	600	8	10	·028	141	17	0		3,665	8	9		·035	·039
330	·032	504	14	1	·024	128	14	2		2,403	8	5		·023	·026
63	·002	81	10	8	·004	50	8	0		455	7	11		·004	·005
85	·053	386	14	1	·018	396	0	5		2,228	9	11		·021	·024
151	·026	336	15	5	·017	76	17	9		1,582	5	1		015	·017
252	·029	367	19	7	·017	99	5	8		1,987	6	7		·019	·021
211	·018	307	3	6	·014	54	0	4		1,634	9	9		·015	·017
421	·033	580	8	2	·027	86	15	11		2,487	16	1		·024	·027
411	·047	648	5	3	·030	217	6	8		3,716	13	6		·035	·040
248	·036	424	18	2	·020	752	18	0		3,329	9	3		·032	·035
666	·086	725	5	8	·034	605	3	0		5,528	10	4		·052	·059
385	·050	406	10	11	·019	291	19	5		2,782	1	2		·026	·030
9,138	1·182	10,831	5	6	·509	7,260	2	0		71,994	17	4		·682	·770
1,332	·165	2,157	2	4	·101	789	1	8		12,303	14	3		·116	·131
7,806	1·017	8,674	3	2	·408	6,471	0	4		59,691	3	1		·566	·639
2,791	·431	4,481	8	10	·210	898	5	4		28,776	7	1		·272	·308
5,832	·831	6,030	5	5	·284	4,111	7	5		45,604	14	11		·432	·488
16,430	2·279	19,185	17	5	·902	11,480	13	1		134,072	5	1		1·270	1·435
		Repairs of tenders—Wages . . .								13,325	12	6		·143	..
		„ „ Materials . .								13,058	5	4		·141	..
		„ „ Total . . .								26,383	17	10		·284	..
		Miles run by tenders								22,252,721				..	..

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Mr. McDONNELL observed that on the Great Southern and Western railway of Ireland the first cost of the engines in the year 1866 was £245,197; at the end of 1875, or the beginning of 1876, the capital cost was £313,246. As far as he was aware, there was no considerable difference between the Great Southern and Western, and the English railways, as regarded the train mile and the engine mile. The usual proportion of train miles to engine miles was 100 to about 125. On the Lancashire and Yorkshire and the North-Eastern railways, it was considerably higher; but on the Great Northern, North-Western, and Great Western it was about 100 to 125. The Great Southern and Western was mainly a passenger line, and the passenger miles were in excess of the others.

Mr. PRICE WILLIAMS said several years ago he had given some statistics relating to rolling stock,[1] and could fully realise the time that must have been devoted to the Paper. He could not entirely agree with the conclusions drawn in regard to the train mileage and the traffic receipts on different railways, and the receipts per engine. The Author had drawn attention to the large increase in the number of engines on the Midland, and had stated that it must not be concluded that an analysis of its working would show more economy than on other railways; but he seemed to have lost sight of the fact, that the large increase in the number of new engines practically represented the incorporation in the Midland system of a large mileage of new railway—the line from Bedford to London opened in 1870, and the Settle and Carlisle railway opened in 1875—and that the reduction in the working expenses per train mile was a natural consequence of the small cost of the repairs and renewals during the first few years' running of the new engines required to work the traffic on the new lines. In Mr. Price Williams's Paper his inquiries had been carried back for many years; and although in the tables submitted by the Author the cost of the repairs and renewals on the Midland railway from July 1868 to December 1875 appeared to be only 2·87*d.*, a reference to the following statement extracted from his tables would show that during the twenty-one preceding years the expenses per train mile were 3·56*d.* (See table on next page.)

He was glad to observe that in the case of the Lancashire and Yorkshire the cost per train mile was 3·19*d.*, inasmuch as during a period of eighteen years it had persistently remained at a very low

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxx., p. 136.

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REPAIRS and RENEWALS of ENGINES for YEARS PRECEDING 1869.

Name of Railway.	Average Number of Years.	Cost per Train Mile.	Cost per Engine per Annum.	Train Miles per Engine per Annum.	Average Money Life.
		£.	£.		Years.
London and North-Western .	11	3·4510	228·72	16,095	10·49
Great Northern	20	2·9360	228·00	18,343	10·53
Midland	21	3·5644	275·24	18,608	8·72
Great Western	5	3·3651	251·84	17,744	10·37
Lancashire and Yorkshire .	18	2·6784	195·00	17,480	12·31
Ten Years subsequent to 1865:—					
Great Southern and Western	10	3·0310	219·50	..	9·90

figure, viz., 2·67*d.* The increase latterly apparent he regarded as a healthy indication that the Lancashire and Yorkshire Company were at length providing their line with adequate locomotive stock. He was also pleased to see that the growth of the receipts on this as on the other lines fully justified the large increase of their rolling stock. The Author had expressed his inability to account for the larger expenditure on the Great Western railway, but the rolling stock of that company was recently in a state of transition, having been almost entirely altered to suit the narrow gauge. The expenses connected with so great a change necessarily increased the cost per train mile, and would no doubt explain the difference which the Author could not account for. In the tables, the Great Southern and Western of Ireland figured conspicuously with the largest cost per train mile, viz. 3·45*d.*; but this was due to the fact that while in the Midland cost per train mile the Author had not included the items "repairs of tools" and "shop expenses," in the Great Southern and Western he had included them, and that appreciably told against the latter line: the shop repairs alone, 0·60*d.*, accounting for the difference. It was quite true, as stated by the Author, that a period arrived when it might be a waste of money to keep on patching and repairing a particular engine; but in the case of a large railway, like the North-Eastern for instance, which possessed more than one thousand engines, there necessarily must be engines in every condition, from the new to that about being relegated to the scrap heap. It would be found, however, as Mr. Harrison had shown to be the case on that railway, that with a number of engines large enough to obtain trustworthy conclusions, the average cost of the repairs and renewals became almost a constant

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quantity;[1] and this would be more and more nearly so in proportion as the types of engines on a line became fewer. For convenience or purposes of account, it might be necessary to keep the items of "Maintenance" and "Renewals" separate, but in his efforts to follow the Author's conclusions he had been obliged to combine them, and the result was much the same as that stated in his Paper. The result of this combination of the items of materials for renewals and repairs, and of wages, as given by the Author was, that in the ten years referred to the total expenditure in maintaining and renewing the stock of engines had been £283,131 (see next page). The number of engines at the commencement had been one hundred and twenty, and at the close of the period one hundred and thirty-eight. The particulars of the annual increase in the number of engines were not given, and he had therefore taken an average for the whole period, and dividing the expenditure by the average number of engines, it appeared that the cost had been £2,195 per engine in ten years, or £219·5 per annum. The average cost per engine of the three types of new engines mentioned in the Paper, viz. £2,174, divided by this annual cost gave roundly ten years, so that there was spent on a single engine in that period its net cost. Therefore the money-life value, as he termed it, of the rolling stock on the Great Southern and Western line appeared to be 9·904 years, or about the same as the average he had formerly obtained. He was not in any way cavilling at this most valuable Paper, his object being to elicit further information. In regard to Table 10, he wished to know how it happened that the number of engines repaired during the ten years was stated to be one hundred and seventy-six, whereas from the Paper it appeared that only one hundred and thirty-eight engines were ever in use at one time? Obviously some of the engines referred to must have gone the way of all engines during the period in question, but the Author had not given the times of their decease. Some such statement as that furnished during a discussion on a Paper by Mr. Robinson[2] should be given. On that occasion Mr. Tomlinson, concurrently with the renewals and repairs, had stated the number of engines renewed in each year. He gathered from Table 10, that the first eleven engines were practically moribund at the time the Paper was written, inasmuch as the average life per engine in miles was stated to be 465,471 miles. Now taking 20,000 miles as the average performance of an engine

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxx., p. 203.
[2] *Ibid.*, vol. xxxvii., p. 46.

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GREAT SOUTHERN and WESTERN RAILWAY.—MAINTENANCE and RENEWALS of LOCOMOTIVES DURING TEN YEARS (1865 to 1875) INCLUDING the ENTIRE RENEWAL of SIXTY-FOUR ENGINES and THIRTY-FOUR TENDERS (ABSTRACTED from TABLES 4 and 5).

—		Materials. £.	s.	d.	Per Train Mile. d.	Wages. £.	s.	d.	Per Train Mile. d.
Engines.									
A Boiler	Renewals	30,643	0	11	·328	6,332	7	3	·067
	Repairs	13,544	17	2	·145	*			*
B Smoke-box, &c.	Renewals	4,277	16	9	·046	5,252	17	2	·056
	Repairs	2,464	8	11	·026	*			*
C Wheels, frames, &c.	Renewals	26,834	13	0	·287	5,505	17	0	·059
	Repairs	24,184	4	6	·229	*			*
D Machinery	Renewals	8,917	13	2	·095	12,014	19	7	·129
	Repairs	23,490	15	3	·252	*			*
E Mountings	Renewals	7,190	7	4	·077	2,416	6	5	·026
	Repairs	5,528	10	4	·059	*			*
F Painting, &c.	Renewals	2,696	8	4	·029	1,381	1	5	·015
	Repairs	2,782	1	2	·030	*			*
* Wages for repairs		..			..	74,881	2	0	·796
		152,554	16	10	1·633	107,284	10	10	1·148
Tenders—									
	Renewals	13,610	18	8	·146	4,563	8	10	·049
	Repairs	13,058	5	4	·140	13,325	12	6	·143
		179,223	15	10	1·919	125,173	12	2	1·340

Cr. Old Materials—

	£.	s.	d.	Per Train Mile.
Renewals	8,961	15	4	·096
Repairs	12,303	14	8	·132
	21,265	9	7	·228

Cr. 21,265 9 7 ·228

Net materials	157,958	6	3	1·691	
Wages	125,173	12	2	1·340	
Total renewals and repairs	283,131	18	5	3·031	
Ratio of materials to wages	55·79 per cent.			44·21 per cent.	
	100				

Average number of effective engines during the period (*vide* Table, p. 4) $= \frac{120 + 138}{2} = 129.$

Average cost per engine during 10 years $= \frac{£283,132}{129} = £2,195.$

Average cost per engine per annum $= \frac{£2,195}{10} = £219·5.$

Average "money life" $= \frac{2,174·8}{219·5}$[1] $= 9·90$ years.

Average money life of engines on twelve of the principal English railways, *vide* "Maintenance and Renewals of Railway Rolling Stock," by R. Price Williams, = 9·902 years.

[1] Net cost of the entire renewal of a single engine (see Table 4), £2,174·8.

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in each year, which was in excess of what really happened on the Great Southern and Western line, it appeared that the average age of the eleven engines in the first column was twenty-three years; of the twenty engines in the second column, eighteen years; of the thirteen engines in the third column, twenty-one years; and of the ten engines of the new or standard type, seven years and three-quarters. The mean average of the whole of the one hundred and seventy-six engines would appear from the following analysis to be twelve years:—

AVERAGE AGE of ENGINES, CALCULATED from MR. MCDONNELL'S DATA.

Number of Engines.	Average Life per Engine in Miles.	Life in Years, taking 20,000 Train Miles per Annum as the Average.
11	465,471	23·27
20	388,028	19·40
13	424,523	21·22
10	157,369	7·86
20	157,066	7·85
10	85,140	4·25
10	239,947	11·99
8	397,009	19·85
17	288,336	14·41
8	316,880	15·84
49	103,818	5·19
176		11·95

During a discussion on a previous Paper, Mr. Harrison had drawn attention to an important fact connected with rolling stock as a test of its condition. He said that wherever the average life exceeded half the ultimate life, it was an indication that the rolling stock was not being maintained up to a fair standard. The more he had inquired into it the more satisfied he was that this dictum of Mr. Harrison's was reliable. In the present case, taking all the moribund engines and the sixty-four engines renewed, the average life approached, if it did not indeed exceed, the limit of safety; so that the sixty-four renewed types of engines were seasonable additions to maintain the efficiency of the locomotive stock. From the information formerly furnished by Mr. Webb for his Paper on this subject, the quantity of labour and materials was carefully and fully gone into, and on a reference to the tabular statement he had prepared from the data supplied in the Paper, it would be seen that the ratio of materials to labour was nearly the same as in the case of the Author's new types of engines.

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In the Paper on railway rolling stock, the cost of materials was said to be 78 per cent., while that of wages was 22 per cent. On the Great Southern and Western the proportion of materials to wages was 73 to 27 per cent. in the first construction of the new engines, while in the cost of the renewal of sixty-four engines and thirty-four tenders, the materials amounted to 69 per cent., and wages to 31 per cent. The cost of repairs, however, gave 45 per cent. for materials, and 56 per cent. for wages. Repairs and renewals taken together showed that 55·79 per cent. of the cost was in respect of materials, and 44·21 per cent. for wages.

RATIO of MATERIALS to LABOUR.

—	Materials.	Wages.
	Per cent.	Per cent.
Engine given in "Maintenance and Renewal of Railway Rolling Stock," by R. Price Williams	78·09	21·91
Great Southern and Western Railway.		
First cost of construction of the three classes of engines (Table 2) 64	72·86	27·14
Cost of renewals of 64 engines and 38 tenders (Table 4) . . .	69·46	30·54
Cost of repairs (Table 9) . . .	45·34	54·66
Repairs and renewals taken together (Tables 4 and 9) . .	55·79	44·21

Mr. W. ADAMS thought the Paper would prove of great value, especially for purposes of reference. He noticed in the Paper an extraordinary mileage for tubes. The mileage of the tubes in the passenger engines was stated to be 436,964 miles, and in the goods engines 290,467 miles. Some time ago he had occasion to ascertain the mileage that the tubes of the Great Eastern railway were performing, and he found it a task of no little difficulty, because tubes did not wear out wholly. They generally burned out at the fire-box end, became very thin, and had to be pieced. A piece had to be cut off until the stout part of the tube was reached, and a new end had then to be brazed on. Sometimes that process had to be repeated two or three times during the life of a tube. With the pieced tubes and the new tubes he got into some little confusion. He found the only reliable way was to

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go back for some years, and he took an account of all the sets of tubes that had been put in from 1868 up to the date when he was endeavouring to obtain the mileage. He took all the sets of tubes that were put in, and all the new engines and new boilers that had been made, and counted so many sets of tubes for each one, and the result was that for eight years the total number of sets of tubes put in had been 667. He then took the total mileage performed during that period, and dividing it by the number of sets of tubes found it to be 120,197 miles. He should be pleased to hear the circumstances under which the Author had been able to get so large a mileage from the tubes. The water throughout the Great Southern and Western district was, he believed, very pure, and he also judged that the work was not distressing to the engines, because the greatest destruction of tubes was in engines that did the hardest work. His personal experience was that the tubes wore away mostly 5 inches or 6 inches from the fire-box tube plate, and at the upper part. The flame as it turned rapidly into the tube seemed to cut it away there. Another question he wished to ask was as to the thickness of the tubes. Some engineers used No. 10 wire gauge, others No. 12, and the difference between No. 10 and No. 12 was probably half a lifetime. Although the gauge of the Great Southern and Western railway was a few inches wider than in England, it did not appear that advantage was taken of this to give more bearing surface to the axle-boxes. The driving axles of the engines were 7½ inches long, or as short as was generally the case in this country, but in recent practice the length had been increased to 9 inches. He assumed the proportions adopted on the Great Southern and Western were those that had been found to be best in actual work, but as the desire had frequently been expressed to have a little wider gauge, so as to give more room for the working parts, it would be interesting to know what the Author's experience had been, and whether with a gauge of 5 feet 3 inches he had not found it necessary to give more bearing surface.

Mr. J. Armstrong remarked that the Paper must have cost the Author a good deal of time and labour, and no doubt it would be useful to refer to hereafter. With regard to the statement in the Paper that "the expenditure on the Great Western for wages, nearly 2*d.* per train mile, is much higher than on the other lines, on which it only amounts to 1½*d.*, and the Author is unable to find any explanation for it, as the increase appears too large to be accounted for by any difference in the form of accounts," he might observe that the Great Western had both broad

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gauge and narrow gauge, while Mr. McDonnell had been fortunate in having only one gauge. The broad gauge of course was a little more expensive than the narrow gauge. The Author could not account for the expenditure for wages being higher on the Great Western, but if he had written to Swindon, as he had sometimes done, he would have received a clear explanation, and been able to make the Paper correct on that point. No doubt the wages on the broad gauge alone were a little higher, but at the present time the wages on the two gauges were only a fair average. However, it was simply a matter of bookkeeping. Mr. McDonnell would purchase a great deal of his work, as, for instance, the wheels of the goods engines, and those wheels he would regard as materials, and the same observation would apply to almost everything else about the engines; but the Great Western made their own wheels. In the forgings for a set of wheels about 52 per cent. of the total cost would be wages, and Mr. McDonnell would charge it all as material. With regard to crank axles, the wages were about 60 per cent., which also the Author would charge as material. The same thing might be said of straight axles, where the wages were 40 per cent., and cylinders 40 per cent. It had been the practice of the Great Western for many years to charge these things directly as "wages" and "materials" instead of passing them through the stores account and showing their whole cost as "materials." There were other reasons why the Great Southern and Western would seem to be working tolerably cheap. Comparing that line with the Great Western, the Great Northern, the Midland, or the London and North-Western, it had a great advantage in the matter of gradients. In many parts of the Great Western line, such as the mineral districts, an engine would only travel about 60 miles a day, not more than half of the ordinary running on an Irish railway. Then the proportion of passenger trains to goods trains had a close relation to the expenditure, either for repairs and renewals, or for running expenses. The Great Southern and Western were fortunate in their earnings of goods trains, getting as much as 7*s.* 8*d.* per mile, a higher amount than was obtained on any of the English railways that had a mineral traffic, such as the Midland, the Great Northern, the Great Western, or the London and North-Western. If the Great Western railway goods manager could get 7*s.* 8*d.* per mile for goods trains he would not trouble the locomotive department about carrying loads so much as he was in the habit of doing, in fact it would get rid of his complaints altogether; but the difference was well known between carrying merchandise in a covered wagon and carrying raw material such as coal, or

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limestone, or iron ore. For instance, from South Wales to Swindon two engines were required to bring a little more than a load of forty wagons with 10 tons in each, while one engine would take 400 tons from Swindon to London. That was a much heavier load than the Author would get in Ireland with his engines. The Great Western earned 5*s.* 7*d.*, the London and North-Western, 6*s.* 4*d.*, the Midland, 5*s.* 7*d.*, the Great Northern, 5*s.* 5*d.*, and the Lancashire and Yorkshire, which was exceptionally placed in a cotton district, earned 7*s.* 4*d.* per mile. The Paper stated that the gradients on the Great Southern and Western were pretty good, with two exceptions. He submitted a table of the principal gradients on the Great Western railway, which showed that in this respect the Great Southern and Western line was more favourably situated than the Great Western railway :—

Gradient.	Length of Gradient.[1]		
	Ascending.	Descending.	Total.
	Miles.	Miles.	Miles.
Steeper than 1 in 40 . . .	5·6	0·4	6·0
1 in 40 and steeper than 1 in 45 . . .	8·5	4·8	13·3
1 in 45 „ „ „ 1 in 50 . . .	21·0	4·9	25·9
1 in 50 „ „ „ 1 in 60 . . .	34·0	26·9	60·9
1 in 60 „ „ „ 1 in 70 . . .	50·4	35·2	85·6
1 in 70 „ „ „ 1 in 80 . . .	37·6	35·1	72·7
1 in 80 „ „ „ 1 in 90 . . .	54·1	36·9	91·0
1 in 90 „ „ „ 1 in 100 . . .	36·8	28·6	65·4
1 in 100 „ „ „ 1 in 110 . . .	67·4	69·9	137·3
1 in 110 „ „ „ 1 in 120 . . .	25·5	22·2	47·7
1 in 120 „ „ „ 1 in 150 . . .	68·1	73·2	141·3
1 in 150 „ „ „ 1 in 200 . . .	94·1	88·2	182·3
Total steeper than 1 in 200 . . .	503·1	426·3	929·4

All this had a bearing on the working of traffic. On the steepest gradients at least two engines were required to take such a load as one engine could take from Swindon to London, or as the Author could take on the Great Southern and Western railway. As regarded repairs and renewals, it was stated that the average of the wages and materials on the Great Southern and Western was 3·451*d.*, and on the Great Western it was only 3·22*d.*, so that the two items together were less than on the Great Southern and Western, and nearly the same as on the Great Northern; but he was sorry to find that in all these matters the Author had separated the working expenses from the repairs. As a rule, he thought

[1] The ascending and descending gradients were taken as on the down journey from London.

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that where coal was about the same price the running expenses afforded the fairest and best test. It would not be on the Irish line, where more had to be paid for the coal; but on the English railways mentioned by the Author it was as fair a test as could be to take the working expenses per train mile, and the cost per cent. of locomotive power upon the earnings. He had been pleased to hear Mr. Price Williams refer to what the Great Western had done during the last few years. In the year 1867, the Royal Commission on railways proposed that the broad gauge should be altered to the national gauge, and to do that £2,000,000 were to be lent to the Great Western Company on the same terms as the loans to the Irish railways; but Ireland had got the best of it in that respect, because the Great Western had not taken advantage of that proposal, and the Directors had decided to charge the whole of the rolling stock to working expenses. The broad gauge was attacked section by section, and turned into narrow gauge, the stock being found out of working expenses. The whole of that had been done without increasing their expenses beyond the average of the English railways. It had been said that the Great Western had been rather backward in trying experiments; but he considered that change of gauge was the greatest experiment tried on any railway for the last twenty years. For instance, the South Wales line and some of its branches were broad gauge. The Directors gave instructions that the gauge should be altered to narrow, and that it should be done within fifteen months. Of course, while the broad gauge was being used, the stock had to be kept up to fair running condition, because Government inspectors and coroners were rather exacting; meanwhile the company had to find one hundred and forty narrow-gauge engines, and the whole of the locomotive stock for the change of gauge on the South Wales line of 208 miles was found out of working expenses. Not a single shilling was charged to capital for any of those engines. During the seven years that the Author had referred to, the Great Western Company made one engine per week out of revenue; so that by the year 1875 the number of broad-gauge engines was reduced to eighty, while they possessed sixty narrow-gauge engines in excess of the capital stock. Then the company thought they saw land ahead; but suddenly they had one hundred and eighty broad-gauge engines from the Bristol and Exeter and South Devon added to their stock. Still, he was quite sure that if the trade of the country continued good, in a few years, when the Directors thought the proper time was come, the other part of the work would be completed. The Paper

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had not referred to the wagons and carriages, but the whole of the expense incurred in that direction was paid for in the same way, except £70,000 or £80,000, which was charged to "Suspense," and the whole of that had been repaid in two years. The goods engine described by the Author was nicely designed, but he thought, with Mr. Adams, that the axle bearing surface might have been a little larger. In the narrow gauge the inside bearing was 8 inches on the Great Western, but every railway had its speciality. On the Great Southern and Western railway the passenger engine weighed 30 tons, and on the Great Western there was a similar engine; but while the Irish engine had a 17-inch cylinder with 22-inch stroke, the Great Western engine had a 17-inch cylinder with 24-inch stroke. The Great Western engine, too, had iron tubes; the Great Southern and Western engine did not always have them of iron; the engine of the former company cost £1,486; of the latter £1,870. The ordinary passenger engines on the Great Western had 16-inch cylinders, 24-inch stroke; on the Great Southern and Western 16-inch cylinders with 20-inch stroke. On the Great Western those engines cost £1,144; on the Great Southern and Western, £1,668. The goods engines on the Great Western, with wheels 1 inch less than on the Irish engine, cost £1,338 13*s.* without tender; on the latter the cost was £1,943. The ordinary tank engines—of which the Great Western had many scores—cost under £1,100. He had prepared some tables, for comparison with those given by the Author, who had not included in the cost of the engines the shop expenses and repairs for tools, which appeared, from Table 9, to amount to about 50 per cent. of the repairs and renewals. He did not refer to interest upon capital, but to the ordinary shop expenses, labourers' wages, general charges, repairs of tools, and the like, which amounted, in the case of the goods engine, to £244 7*s.* 7*d.*, making the total cost of the engine £2,187 8*s.* 1*d.*, or, taking the tender at £453, to £2,641 0*s.* 8*d.*, as compared with the Great Western £1,663 17*s.* 8*d.* The London and North-Western had a similar engine at a still lower cost; it was, however, a single-frame engine, the Great Western being a double-frame, and, consequently, a little more expensive. But it would be unfair to put the Great Southern and Western in the same category with the Great Western or the London and North-Western, which had spent a great deal of money in preparing shops and machinery to make their own stock. The Author had bought a great deal of stock, and had not only to pay the profits of the maker, but interest upon capital. The wages for an express coupled engine on the Great

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Western amounted to £452 18*s.* 5*d.*, on the Great Southern and Western to £637. For a light coupled engine the wages on the Great Western amounted to £409 5*s.* 11*d.*, as against £565 on the Great Southern and Western. For a goods engine the same item was £425 9*s.* on the Great Western, as against £592 on the Great Southern and Western. Mr. Price Williams in 1870[1] had given the total expenditure of the Locomotive Department, which he thought was always the fairest way, although a good deal would have to be taken into account for the traffic on the different lines. The Great Western had the South-Western to compete with very keenly on one side, and the London and North-Western on the other. Unfortunately the Great Western line from Paddington to Exeter was 20 miles farther round than the South-Western, and assuming the Great Western to earn 5*s.* per mile, the South-Western would earn 5*s.* 7*d.* Again, the Great Western line from Paddington to Birmingham was 16½ miles farther than that from Euston to Birmingham; so that if the Great Western earned 5*s.* per mile, the London and North-Western would earn 5*s.* 9*d.* In the same way, between Birmingham and Manchester the London and North-Western would earn 5*s.* 7*d.* against 5*s.* on the Great Western. The London and North-Western, again, would earn 6*s.* per mile between Euston and Chester, as compared with 5*s.* between Paddington and Chester, the route being 34 miles shorter. Of course all that had a bearing on the earnings of the engine to which the Author had referred. Mr. Price Williams had given an extract from a letter written by Mr. Armstrong[2] drawing attention to the difference on the several railways compared, as to the proportions of passenger train miles to goods train miles. On the Great Western it would take 50 per cent. more to work a goods train than to work a passenger train; or, in other words, it would take as much to work 2 miles with a goods train as it would to work 3 miles with a passenger train. On the Great Southern and Western the proportion was—passenger trains 63·4 per cent., goods trains 36·6 per cent. Assuming that the proportion on the other railways to which reference had been made was the same, the Great Western expenses in the half-year ending December 1875 would be £26,000 less than they were; on the London and North-Western £39,000 less, on the Midland £49,000 less, on the Great Northern £13,698 less, and on the Lancashire and Yorkshire £13,643 less. He had

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxx., p. 136.
[2] *Ibid.*, p. 193.

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prepared a statement of the expenses on the Great Western for seven years, similar to that given by Mr. McDonnell, also showing the running expenses. The cost of repairs and renewals on the Great Western was 3·11*d.*, and not 3·22*d.*, as stated by Mr. McDonnell, who had evidently divided the gross expenditure by the net train miles. In 1869 the Great Western had eight hundred and eighty-six engines; they had built fifty-two narrow-gauge engines and renewed two broad-gauge engines, which would be equal to fifty-four, because the broad-gauge engines were to all intents and purposes as good as they were when they were first built—a proportion of 6 per cent. In 1870 they had nine hundred and twelve engines, built fifty-two, and renewed with new boilers, cylinders, &c., three broad-gauge engines and three narrow-gauge—6·3 per cent. In 1871 they renewed 6·7 per cent., in 1872 a little more than 5 per cent., in 1873 a little in excess of 6 per cent., 5·4 per cent. in 1874, 6·7 per cent. in 1875—making an average of 6·07 per cent. They had built during seven years three hundred and seventy-seven narrow-gauge engines, renewed eleven broad-gauge engines and thirty-nine narrow-gauge engines—making a total of four hundred and twenty-seven, the whole cost having been charged to working expenses. The average age of the Great Western engines was 6·1 years. During the whole of this time new engines had been built out of capital, in the proportion of one engine for every 20,000 miles increase of traffic. In 1876 the accounts showed a surplus stock of seventy-nine broad-gauge engines and of seventy-one narrow-gauge, all workable. At the present time not so much value was attached to the broad-gauge engines as to the narrow-gauge. He had prepared a table showing the average life of the iron tubes. The longest lived in a 7-feet engine had run 178,000 miles, and the shortest lived 122,000 miles, the average being 155,000 miles. In the case of the 6-feet 6-inches engine, the highest of eight sets had run 289,000 miles, the lowest mileage being 213,000, giving an average of 248,000 miles. Six engines (6-feet coupled) had run an average of 169,000 miles, the highest being 223,000 miles, and the lowest 96,000 miles. These were all passenger engines. With goods engines the highest life was 155,000 miles, and the lowest 83,000, giving an average of 111,000 miles. With the broad-gauge engines the tubes had lasted longer than they did at present. One engine ran 447,000 miles without the tubes being taken out. Several sets of tubes were taken out before they were done with, in order to examine the boiler. With a 6-feet 6-inches coupled passenger engine the average of twelve sets was 219,000 miles, and with

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a goods engine 178,000. The wire gauge could not be ascertained exactly, but it might be taken as No. 14. The tubes taken out were frequently cleaned, the ends cut off, a little piece welded on, and then put in again. His experience of steel crank axles was not large. The Great Western Company had only twelve before 1872. The life of one of them had been 143,000 miles, the highest being 169,000 miles. The mileage of the iron crank axles of four passenger express engines, 8-feet single driving wheel, double frame, was 278,000, 253,000, 226,000, and 225,000 miles. A four-wheel coupled engine, single frame, ran 272,000 miles. The narrow-gauge engines appeared to have run a greater mileage; they were single driving-wheel engines, with double frames, one of which had reached 305,000, and another 295,000 miles. One six-wheel coupled goods engine had run 316,000 miles, the lowest distance being 232,000 miles.

He wished to refer for a moment to what had been done forty years ago, when the first passenger lines were made. A patent locomotive engine had been turned out by Mr. John Gray, to work expansively, and there was then a keen competition with regard to the consumption of fuel. On that subject a Member of the present Council of the Institution, Mr. Edward Woods, then Chief Engineer of the Liverpool and Manchester railway, had written as follows:—

"*Observations on the Consumption of Fuel and the Evaporation of Water in Locomotive and other Steam Engines, by* EDWARD WOODS, C.E.[1]

"It had become a question whether the Company should not proceed to adapt the expansive gearing to more of their engines; but an engine having now been made to rival the 'Cyclops,' without in any degree increasing the complexity of the gearing, it was considered more desirable to delay proceedings until the simpler method was fully tested by numerous experiments. To accomplish this in the then existing engines was found to be no easy task; for on examination it was discovered that, in many cases, there was no room in the steam chest for valves of greater lap; in others, that it was impossible to increase the length of travel. Therefore it was necessary to prepare, in the first instance, for the sacrifice of at least the cylinders, steam chests, working gear, and inside framing of several engines then needing repair, and eventually, as resources would permit, for replacing the Company's entire stock with new engines, all built according to one model, combining the latest improvements experience had shown worthy of introduction, trusting that the saving in fuel, and in the general expenses of repairs, would speedily repay the Company for the immediate sacrifice. These views fortunately proved to be well founded. The loss was soon recovered; for the saving in the cost of fuel and repairs considerably

[1] *Vide* Tredgold "On the Steam Engine," vol. i., division A., Locomotive Engines, 5th Paper, p. 31. 4to, London, 1850.

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exceeded the outlay, and although during the years 1840, 1841, 1842, the Company turned out from their workshops twenty-four new engines (the cost of the whole being debited to current disbursements, under the head of 'Locomotive Power'), and broke up as many old ones, yet at the same time the total expenses of the locomotive department underwent a gradual reduction from £51,580 per annum, the charge in 1839, to £25,732, the charge in 1842."

TABLE 4.—GENERAL RESULT.[1]

In the year 1838	12,604	tons of coke consumed,
1839	11,754	" "
1840	6,518	" "
1841	4,508	" "
1842	3,393	" "
1843	3,103	" "

TABLE 1.—DISTANCES by GREAT WESTERN RAILWAY COMPARED with COMPETITIVE ROUTES, SHOWING EFFECT on RECEIPTS per MILE.

	Distances.	Receipts per Train Mile. 5s. per Mile on G. W. R. Route, equal on Competitive Route to
	Miles.	s. d.
Paddington to Exeter	194	
Waterloo to "	174	5 7
	20	
Paddington to Birmingham (Snow Hill)	129½	
Euston to " (New Street)	112¾	5 9
	16½	
Birmingham (Snow Hill) to Manchester, *viâ* Market Drayton	94½	
Birmingham (New Street) to Manchester, *viâ* London and North-Western	83½	5 7
	11	
Paddington to Chester.	213¼	
Euston to "	179¼	6 0 nearly.
	34	

[1] *Vide* Tredgold "On the Steam Engine," vol. i., division A., Locomotive Engines, 5th Paper, p. 41. 4to, London, 1850.

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TABLE 2.—COST of LOCOMOTIVE ENGINES and TENDERS

Description.	Express coupled Passenger Engine, 1873.
Cylinders	17 inches diameter × 24 inches stroke.
Wheels	Driving and trailing 6 feet 6 inches diameter.
Weight in working order	31 tons.

Summary of Cost.	Materials. £ s. d.	Wages. £ s. d.	Factory Expenses. £ s. d.	Total. £ s. d.
Boiler complete (not including mountings, lagging, and smoke-box)	382 6 0	58 4 0	32 5 6	472 15 6
Wheels and axles, springs, frame-plates, &c.	297 12 6 Includes steel crank.	86 3 10	51 7 3	435 3 7
Cylinders, connecting rods, valve motion, &c.	52 10 9	74 9 3	45 10 9	172 10 9
Mountings, smoke-box, angle irons, platforms, erecting, painting, and sundries	168 3 5	144 9 4	93 0 2	405 12 11
Total engine	900 12 8	363 6 5	222 3 8	1,486 2 9
Tender complete (average of 220 tenders built from 1870 to 1875)	178 16 5	89 12 0	56 16 3	325 4 8
Total engine and tender	1,079 9 1	452 18 5	278 19 11	1,811 7 5
	Mail Engine.			
Great Southern and Western Railway. Including factory expenses, 50 per cent. on wages — Engine	1,337 0 0	533 13 6	266 16 9	2,137 10 3
Great Southern and Western Railway. Including factory expenses, 50 per cent. on wages — Tender	298 12 7	103 6 8	51 13 4	453 12 7
Total	1,635 12 7	637 0 2	318 10 1	2,591 2 10

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BUILT by the GREAT WESTERN RAILWAY COMPANY.

Light coupled Passenger Engine, 1869. 16 inches diameter × 24 inches stroke. Driving and trailing 6 feet diameter. 27½ tons.													Goods Engine, 1875. 17 inches diameter × 24 inches stroke. Leading, driving and trailing 5 feet diameter. 30½ tons.												
Materials.			Wages.			Factory Expenses.			Total.				Materials.			Wages.			Factory Expenses.			Total.		
£.	s.	d.	£.	s.	d.	£.	s.	d.	£.	s.	d.		£.	s.	d.	£.	s.	d.	£.	s.	d.	£.	s.	d.
259	1	8	52	18	8	25	4	1	337	4	5		340	18	11	56	6	2	31	13	7	428	18	8
218	7	4	72	3	2	39	2	6	329	13	0		222	0	0	78	12	7	58	4	10	358	17	5
39	10	11	65	7	6	30	5	7	135	4	0		44	6	1	68	3	11	42	3	10	154	13	10
156	14	6	129	4	7	56	8	4	342	7	5		171	13	5	132	16	3	91	13	5	396	3	1
673	14	5	319	13	11	151	0	6	1,144	8	10		778	18	5	335	18	11	223	15	8	1,338	13	0
178	16	5	89	12	0	56	16	3	325	4	8		178	16	5	89	12	0	56	16	3	325	4	8
852	10	10	409	5	11	207	16	9	1,469	13	6		957	14	10	425	10	11	280	11	11	1,663	17	8
Ordinary Passenger Engine.													Heavy Goods Engine.											
1,205	19	8	462	1	7	231	0	9	1,899	2	0		1,454	5	3	488	15	3	244	7	7	2,187	8	1
298	12	7	103	6	8	51	13	4	453	12	7		298	12	7	103	6	8	51	13	4	453	12	7
1,504	12	3	565	8	3	282	14	1	2,352	14	7		1,752	17	10	592	1	11	296	0	11	2,641	0	8

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TABLE 3.—TRAIN MILES and LOCOMOTIVE EXPENSES. GREAT SOUTHERN and WESTERN RAILWAY COMPARED with other COMPANIES, HALF-YEAR ENDED DECEMBER, 1875.

Railway.	Traffic Receipts per Train Mile.			Train Miles.			Great Southern and Western compared with other Railways.		Locomotive Expenses.	
	Passenger.	Goods.	Total.	Passenger.	Goods.	Reduced to Equivalent Passenger. 2 Goods = 3 Passenger.	Equivalent Mileage Excess over Great Southern and Western.	Percentage Increase of Expenses of other Companies through Excess Goods Miles.	Net Total.	Reduction in Expenses if proportion of Goods to Passenger Miles were the same as on Great Southern and Western.
	s. *d.*	*s.* *d.*	*s.* *d.*	Percentage of Total Miles.					£.	£.
Great Southern and Western	4 11·8	7 8·9	5 11·9	63·4	36·6	118·3	..	..	52,511	..
Great Western	5 3·5	5 7·8	5 5·9	45·1	54·9	127·4	9·1	7·1	370,854	26,330
London and North-Western	5 2·6	6 4·7	5 10·0	47·3	52·7	126·3	8 0	6·3	623,869	39,304
Midland	5 0·0	5 7·6	5 5·0	34·9	65·1	132·5	14·2	10 7	459,632	49,180
Great Northern	4 10·7	5 5·7	5 2·4	47·0	53·0	126·5	8·2	6·5	210,737	13,698
Lancashire and Yorkshire .	5 3·0	7 4·4	6 3·9	49·3	50·7	125·3	7·0	5·6	243,624	13,643

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TABLE 4.—MILEAGE, LOCOMOTIVE EXPENDITURE, TRAFFIC RECEIPTS, &c., on the GREAT WESTERN RAILWAY for the SEVEN YEARS from FEBRUARY 1, 1869, to JANUARY 31, 1876.

Gross Train Miles.	Salaries, Office Expenses, and Superintendence.	Running.				
		Wages.	Coal and Coke.	Water.	Oil, Tallow, and Stores.	Total.
	£.	£.	£.	£.	£.	£.
129,074,957	110,506	1,258,373	1,170,216	108,618	130,038	2,667,245
	d.	d.	d.	d.	d.	d.
Per train mile . .	0·20	2·33	2·17	0·21	0·24	4·95

Repairs and Renewals.			Repairs of Workshops, Sheds, and Engine Turntables.	Gas.	Total Locomotive Expenses.	Less Credit for Power supplied to other Lines, and for Ballasting.
Wages.	Materials.	Total.				
£.	£.	£.	£.	£.	£.	£.
1,011,174	661,417	1,672,591	36,622	29,895	4,516,859	158,082
d.	d.	d.	d.	d.	d.	
1·88	1·23	3·11	0·06	0·05	8·39	

Net Locomotive Expenses.	Percentage on Traffic Receipts.	Net Train Miles run. Corresponding with Net Expenses and Traffic Receipts.				
		With Passengers.	With Goods.	Total.	Percentage on Total Train Miles.	
					Passenger.	Goods.
£.						
4,358,777	12·76	59,401,913	66,440,839	125,842,752	47·2	52·8
d.						
8·31	..	..	..	..	..	..

Traffic Receipts.		
Passengers.	Goods.	Total.
£	£.	£.
15,760,511	18,396,031	34,156,542
s. d.	s. d.	s. d.
5 3·67	5 6·45	5 5·14

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TABLE 5.—GREAT WESTERN RAILWAY. RENEWAL of LOCOMOTIVE STOCK.
Number of Engines renewed each year compared with Capital Stock—1869 to 1875.

Year.	Number of Engines in Capital Stock.	Number of Engines built or renewed during Year.				Percentage of Renewals on Capital Stock.
		New Engines complete.	New Boilers, and Engines reconstructed.		Total.	
			Broad Gauge.	Narrow Gauge.		
1869	886	52	2	..	54	6·1
1870	912	52	3	3	58	6·3
1871	941	58	3	2	63	6·7
1872	991	52	..	2	54	5·4
1873	1,021	54	3	5	62	6·0
1874	Transferred from L. & O. and Llanelly 33 / 1,085	52	..	8	60	5·4
1875	1,162	57	..	19	76	6·7
	Average Stock . 1,005	377	11	39	427	6·07

TABLE 6.—GREAT WESTERN RAILWAY. AVERAGE MILEAGE of IRON TUBES in LOCOMOTIVE ENGINES.

No. of Sets taken.	Class of Engine, Great Western Railway.	Mileage.			Remarks.
		Highest.	Lowest.	Average.	
	NARROW GAUGE.				
	Passenger Engines.				
11	7 feet, "Sir Watkin" class .	178,889	122,030	155,920	
8	6 feet 6 inches, single driving-wheels, Beyer's class .	289,000	213,256	248,238	
6	6 feet, coupled	223,978	96,680	169,810	
	Goods Engines.				
15	6 wheels coupled, standard goods	155,275	88,214	111,912	
	BROAD GAUGE.				
	Passenger Engines.				
12	6 feet 6 inches, coupled . .	447,057	125,487	219,777	
	Goods Engines.				
12	6 wheels coupled, 5-feet wheels	265,953	113,484	178,374	

The exact wire gauge of the tubes cannot be given, but in the majority of instances it would be No. 14.

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TABLE 7.—GREAT WESTERN RAILWAY. AVERAGE AGE of LOCOMOTIVE ENGINES (Capital Stock) December 1875.

Date of Construction.	Number of Engines: Narrow Gauge.			Number of Engines: Broad Gauge.			Number of Engines: Broad and Narrow Gauge.		
	Passenger.	Goods.	Total.	Passenger.	Goods.	Total.	Passenger.	Goods.	Total.
1856	2	16	18	..	..	..	2	16	18
1857	4	12	16	..	..	..	4	12	16
1858	1	10	11	..	..	..	1	10	11
1859	5	2	7	..	2	2	5	4	9
1860	2	6	8	..	..	..	2	6	8
1861	8	24	32	..	13	13	8	37	45
1862	25	28	53	..	6	6	25	34	59
1863	5	..	5	7	5	12	12	5	17
1864	11	36	47	8	..	8	19	36	55
1865	6	14	20	17	..	17	23	14	37
1866	27	33	60	9	3	12	36	36	72
1867	1	56	57	..	..	..	1	56	57
1868	30	35	65	..	..	..	30	35	65
1869	88	1	89	..	1	1	88	2	90
1870	11	73	84	3	..	3	14	73	87
1871	23	67	90	3	..	3	26	67	93
1872	14	91	105	..	..	..	14	91	105
1873	27	72	99	3	..	3	30	72	102
1874	35	85	120	..	..	..	35	85	120
1875	39	67	106	..	..	..	39	67	106
Total Capital Stock. . .	364	728	1,092	50	30	80	414	758	1,172
Average Age in Years. .	6·0	5·7	5·8	9·1	12·8	10·5	6·3	6·0	6·1

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TABLE 8.—GREAT WESTERN RAILWAY. MILEAGE of STEEL CRANK AXLES.

Class of Engine.	Axles which have Broken.				Axles which are still running.			
	Number of Axles.	Mileage.			Number of Axles.	Mileage.		
		Highest.	Lowest.	Average.		Highest.	Lowest.	Average.
NARROW GAUGE.								
Passenger Engines.								
Express Engines: Single driving wheels, 7 feet diameter; Frames, double; Cylinders, 18 inches by 24 inches	7	66,744	36,094	39,880	13	88,207	111	42,734
Single driving wheels, 7 feet diameter; Frames, double; Cylinders, 17 inches by 24 inches	13	143,630	16,653	58,694	14	111,656	8,846	53,221
Four wheels, 6 feet 6 inches diameter, coupled; Frames, single; Cylinders, 17 inches by 24 inches	None broken.				11	146,887	47,522	93,736
Goods Engines.								
Six wheels, 5 feet diameter, coupled; Frames, double; Cylinders, 17 inches by 24 inches	2	49,422	3,186	26,304	24	113,616	23,423	66,145
BROAD GAUGE.								
Goods Engines.								
Six wheels, 5 feet diameter, coupled; Frames, single; Cylinders, 17 inches by 24 inches	2	169,024	158,681	163,852	..	..	..	..

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TABLE 9.—GREAT WESTERN RAILWAY. MILEAGE of IRON CRANK AXLES.

	Mileage.
BROAD GAUGE.	
Passenger Engines.	
8 feet single driving wheels, double frames	278,202 253,098 226,631 225,242
4 wheels (6 feet diam.) coupled, single frames	272,138
Goods Engines.	
6 wheels (5 feet diam.) coupled, single frames	282,866
NARROW GAUGE.	
Passenger Engines.	
Single driving wheels, double frames	305,000 295,000
4 wheels coupled, double frames	323,352 251,600 247,928
4 wheels coupled, single frames	301,029
Goods Engines.	
6 wheels (5 feet diam.) coupled, double frames	316,000 301,567 296,015 249,000 245,554 241,536 232,858
6 wheels (5 feet 3 inches diam.) coupled, double frames	282,374

NOTE.—The axles referred to above are selected from those which have failed during the last three years.

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TABLE 10.—MILEAGE, LOCOMOTIVE EXPENDITURE, TRAFFIC RECEIPTS, &c., of the GREAT SOUTHERN and WESTERN, COMPARED with the MIDLAND GREAT WESTERN, of IRELAND, RAILWAYS, for the HALF-YEAR ENDING DECEMBER 1875.

Railway.	Engines in Stock. Capital Account.	Gross Train Miles.	Salaries, Office Expenses, and Superintendence.	Running.				
				Wages.	Coal and Coke.	Water.	Oil, Tallow, and Stores.	Total.
Great Southern and Western.	139	1,275,170	£. 1,796	£. 11,477	£. 17,626	£. 1,329	£. 1,746	£. 32,178
Per train mile .	..	..	d. 0·33	d. 2·16	d. 3·31	d. 0·25	d. 0·33	d. 6·05
Midland Great Western . .	92	833,065	369	6,676	11,283	574	1,423	19,956
Per train mile .	..	..	d. 0·10	d. 1·92	d. 3·25	d. 0·16	d. 0·41	d. 5·74

—	Repairs and Renewals.			Gas.	Total Locomotive Expenses.	Percentage on Traffic Receipts.
	Wages.	Materials.	Total.			
Great Southern and Western.	£. 7,538	£. 10,130	£. 17,668	£. 869	£. 52,511	£. 13·7
Per train mile .	d. 1·41	d. 1·90	d. 3·32	d. 0·16	d. 9·88	..
Midland Great Western . .	5,926	4,830	10,756	..	31,081	13·1
Per train mile .	d. 1·71	d. 1·39	d. 3·09	..	d. 8·95	..

—	Net Train Miles run. Corresponding with Net Expenses and Traffic Receipts.				
	With Passengers.	With Goods.	Total.	Percentage on Total Train Miles.	
				Passengers.	Goods.
Great Southern and Western	808,052	467,118	1,275,170	63	37
Midland Great Western . .	505,990	327,075	833,065	61	39

—	Traffic Receipts.			
	Passengers.	Goods.	Total.	Per Locomotive Engine.
Great Southern and Western.	£. 201,455	£. 180,896	£. 382,351	£ 2,750
Per train mile .	s. d. 4 11	s. d. 7 8	s. d. 5 11	..
Midland Great Western . .	110,914	125,720	236,634	2,572
Per train mile .	s. d. 4 4	s. d. 7 8	s. d. 5 8	..

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Mr. Henry Hughes was pleased to notice that so much importance had been attached to financial results and conditions with regard to locomotive engines, and was astonished at the clear manner in which Mr. Armstrong had explained the apparent difference in the cost of labour on the Great Western as compared with that of other railways. He believed it was also possible to explain why the Great Western locomotive engines appeared to cost less than those of other companies. He would ask whether there might not be some outlay of capital, or some amount of labour placed to general charge, which, in the case of ordinary engine makers, would have to be provided for in the regular way. He hoped the time would be far distant when engineers would cease to be indebted to the industry and enterprise of such firms as the Stephenson's, Kitson's, Sharp, Stewart and Co., Peacock's, and others. The railway companies in assuming gigantic monopolies had become coal getters, chair founders, wheel and axle forgers, locomotive carriage and wagon builders, steamboat owners, and hotel keepers. He was glad for the sake of the shareholders that they had refrained from becoming iron smelters. He believed the low prices that had been mentioned were quite exceptional. Where the contracts were given out the prices appeared somewhat high, but in other instances the makers were well looked after. On referring to the accounts, he observed that last year twenty engines had been charged to capital, and in the half-year in question twenty-four. He hoped some locomotive engineer would explain the differences to which reference had been made, and would show that the engine makers of the country had only been charging a moderate profit, and were but just able to maintain the position they ought to occupy.

Mr. Stirling remarked, through the Secretary, that railways differed very much from each other in the nature of their traffic, and consequently in the cost of maintenance. The lifetime of a boiler on the Great Northern was ten years, and he had to make about sixty per annum, the number of engines being five hundred and ninety-four. A copper fire-box lasted from three to five years, and a set of tubes from two to four years, so that any comparison with railways where the boilers lasted from twenty to thirty years would be entirely inappropriate. The renewals of engines had for the last ten years been at the rate of thirty-eight per annum, and there was at present no engine on the railway more than twelve years old. The cost of engine repairs and renewals for 1876 was 2·66*d.* per train mile; the number of miles run per engine 24,500 per annum. The cost of the first-class express bogie engine, with tender,

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was £2,018, including shop expenses, general charges, &c. Their average load was eleven vehicles, and consumption of coal 25 lbs. per train mile. He had not been encouraged in his attempts to introduce crucible cast-steel cranks for engines. On an average they did not give such good results as Yorkshire iron on 7-feet wheels. He had a few Bessemer cranks running, but could not speak to their durability. Cranks would run much longer with single frames than with double ones. He had no particulars of the comparative durability of Bessemer and crucible cast-steel tires, as there had not been any Bessemer tires worn out yet; but both had two and a half to three times the lifetime of iron.

Sir JOHN HAWKSHAW, Past-President, desired to make one observation striking at the root of the statistical comparisons. Train mileage, which was used as a divisor in all cases, meant a very different thing on different railways. Take the case of an engine on the Lancashire and Yorkshire railway, starting from Normanton to go to Manchester or Liverpool, or from Todmorden to Liverpool, it began with a small number of wagons, and stopped at numerous stations to take up others, being nearly as often engaged in stopping and shunting as in running. The mileage would be reckoned from Normanton to Manchester or Liverpool; but on a line where there were stations every 2 miles, and where a train had to stop at every station, the train mileage meant a very different thing from that on a line like the Great Western or the South-Eastern. That was the reason why all such statements should be taken with a great deal of caution. Statistics were valuable if they could be correctly arrived at and rightly treated; but from what he knew of the figures he was sure that correct results were not obtained, owing to the circumstances to which he had referred.

Mr. WOODS said he had been anticipated by the remarks of Sir John Hawkshaw, which he himself could fully confirm, and also of Mr. Armstrong, who had pointed out that it was impossible to compare the cost of working on even different portions of the same line. Mr. Armstrong had referred to the difference in the work that had to be done in conveying a given load from the South Wales District to Swindon, and from Swindon to London, involving in the one case almost double the locomotive power that was required in the other. About twenty years ago he was deputed by the London and North-Western Company, in connection with Mr. W. P. Marshall, M. Inst. C.E., to institute a comparison between the working of the engines on the southern and the northern

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divisions of that line. On looking into the matter, and considering all the points of difference between the two sections of the line—the Grand Junction, on which the gradients were severe, and the section between London and Birmingham, where they were comparatively light—it was found almost impossible to make a comparison without bringing the engines of the one section to work the traffic on the other. Having full permission to do as they pleased in that respect, they had the Grand Junction engines brought to the southern section; and with those engines the most important goods and passenger trains were alternately worked by the engines of the respective divisions, so that in that way a fair comparison was made. Mr. Armstrong had quoted from a Paper which Mr. Woods had written many years ago, giving the results of the working of the Liverpool and Manchester line. That Paper contained a correct record of the facts. It was quite true that a great reduction in the expenses was effected by the alterations and improvements of the engines then carried out. That, however, was not the work of one individual, but of many. He happened to be connected with the line at that time, and of course took a great interest and a prominent part in procuring those results. The work was carried out in a succession of years, and it resulted in the line being stocked with a new set of engines out of revenue. In the Author's figures with regard to repairs, the item of "sundries" appeared to be a large one, and he should be glad to know if any explanation could be given of it.

Mr. Kirtley remarked, through the Secretary, that the Paper contained much valuable information. The statistics of the cost of the different materials comprised in locomotives were seldom, if ever, got out by the larger railway companies, such as the London and North-Western, Midland, Great Western, or Great Northern, on account of the extra staff and practical supervision that would be required to insure accuracy. The accounts of the locomotive departments of railways were generally kept under two heads—running and repairs, including wages in both cases, except on those lines where additional engines were built annually and charged to capital. For these a separate account was kept of materials and wages, including a percentage (25 to 33) for general charges, viz. wages of foremen, clerks, and labourers, coal and coke, and small tools used in the factory, which could not be easily separated for the additional engine account, nothing, however, being allowed for interest on capital expended on buildings or plant or for depreciation of the same. Great care should therefore be taken before accepting these figures as to the actual or market

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value of the engine, or comparing them with a contract price by locomotive engine manufacturers. The cost of producing materials such as plates, tires, and axles must also be considered. Some of the larger railway companies had every facility for manufacturing these; while, on the other hand, others had to purchase them, in which case, although under contract, a profit was included. Whether the engines were built for renewals or for additional stock, there must be a considerable difference in the cost of production, according to the manner in which the material was provided. He quite agreed with the Author, that the expenditure required to maintain locomotives in an efficient state varied according to the nature of the traffic on the line, and the age of the stock; the number of different classes of engines, the state of the permanent way, and the curves and gradients also materially affected both the cost of working and repairs. He did not consider that additional engines required to meet the growth of traffic, if in a proportionate ratio, would affect the cost of repairs, if plant and machinery were also provided. There was some difficulty, therefore, in comparing the accounts of the various railways, and in analysing them in a satisfactory manner. With respect to the number of engines, and the traffic receipts of the principal lines tabulated in the Paper, nothing required special comment. In the case of the Midland, the increase in the number of engines above the proportionate increase of traffic receipts might, he thought, be explained by the fact that new and additional lines were in the course of construction: for instance, the Settle and Carlisle, 80 miles in length. Other matters affecting these comparisons were the number of train miles per engine per day, which varied according to the class of traffic and the district through which the engines worked, the percentage of passenger and goods traffic, and the number of shunting engines used on the line. The latter were generally included in the total stock published in the half-yearly statements, in respect of which no train miles were allowed, and as far as the locomotive department was concerned this might mean a heavy debit.

The cost of repairs, including renewals of engines and tenders had been generally taken at about 3*d.* per train mile (1½*d.* for wages and 1½*d.* for materials) on the large lines; but this was not always sufficient to maintain locomotive stock, especially upon some of the smaller lines, particularly if a large number of engines were running under the average daily mileage. The heaviest items of expenditure were boilers, fire-boxes, tubes, tires, and crank

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axles; on lines where the water was bad, the life of the fire-boxes and tubes was much reduced.

The life of boilers on the Midland railway, between the years 1847 and 1874, had been, for the three classes of engines, viz. single and coupled passenger, and six-coupled goods engines:—

Life in Years.			Life in Miles.			Average Miles per Annum.
Highest.	Lowest.	Average.	Highest.	Lowest.	Average.	
			Single Passenger Engines.			
18	11	14	370,755	191,628	299,194	21,701
			Boilers that underwent heavy repairs.			
25	20	23	640,299	479,477	550,590	23,928
			Four-coupled Passenger Engines.			
14	10	13	435,144	282,265	351,846	26,611
			Six-coupled Goods Engines.			
14	10	12	381,948	220,493	309,882	24,582
			Boilers that underwent heavy repairs.			
25	17	20	496,007	364,402	427,092	21,192

And on the London, Chatham, and Dover railway the life of boilers of four-coupled passenger and tank engines had been:—

Life in Years.			Life in Miles.			Average Miles per Annum.
Highest.	Lowest.	Average.	Highest.	Lowest.	Average.	
			Four-coupled Passenger Engines.			
14	13	13	398,807	353,171	369,992	27,694
			Tank Engines.			
15	14	14	371,852	229,532	306,652	21,191

On the Chatham and Dover line the average life of copper fire-boxes had been:—

Four-wheel coupled	passenger	engines	. . . .	161,334 miles
Six „	„	goods	. . . . .	74,403 „
Four „	„	tank	„	301,221 „

The life of the fire-box of tank engines was longer than that of main-line engines, which he considered was due to the lighter class of work they were engaged upon, and to the use of feed-water heated by condensation.

The average mileage of tubes given by the Author, of those taken out and also in use, appeared high, and required some

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explanation of their thickness when new, their diameter, and the water spaces. The average mileage of brass tubes, 2 inches in diameter, on the Midland railway for all classes of engines varied from 80,000 to 110,000; the tubes were 10 B.W.G. at the fire-box end, and 12 B.W.G. at the smoke-box end. The following tabulated statement showed the average life of 2-inch tubes on the London, Chatham, and Dover railway. The tubes when new were 10 B.W.G. at the fire-box end, and 12 B.W.G. at the smoke-box end, and were composed of 70 parts copper to 30 parts spelter.

Main-line Passenger Engines.

	Set's.	Miles.	
Brass tubes	(18), first life	71,706	pieced
„ „	(1), second life	40,445	worn out
Average total life of 10 sets		129,790	
Copper tubes	(5), first life	108,042	pieced and still running
Iron „	(2), total	94,418	worn out

Goods Engines.

Brass tubes	(12), first life	26,550	pieced
„ „	(6), second life	14,001	„
„ „	(4), third life	14,852	worn out
Average total life of 4 sets		54,893	
Copper tubes	(5), first life	53,173	pieced and still running
Electro iron	(1), total	44,776	worn out

Tank Engines.

Brass tubes	(4), first life	173,147	pieced
„ „	(3), second life	77,601	„
„ „	(1), third life	37,229	worn out
Average total life of 10 sets		261,957	

There had been considerable saving of late years by the use of steel tires, not only in the longer life got out of them, but also in the increased length of time an engine could be kept running before the wheels required turning up. He found on the Midland railway that, with the heaviest class of engines, only an average of from 50,000 to 60,000 miles could be got out of iron tires, but when they were replaced by crucible cast-steel, an average mileage of from 120,000 to 150,000 miles (or more than twice that of iron) was obtained; the thickness of the tires in both cases being $2\frac{3}{8}$ inches on the tread when finished. Bessemer steel tires did not give such a good average mileage as crucible cast steel by about a third. The Author had not stated the thickness of the tires on the Great Southern and Western railway; and as the mileage appeared large, he presumed it to be accounted for by additional thickness when new, or lighter weights on the wheels.

The life of iron crank axles of all makes, on the Midland rail-

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way, varied from 50,000 to 350,000 miles. The average mileage of crank axles which broke while running, for the six years 1868 to 1873 inclusive, was equal to 3·66 per cent. breaking each year while running. About 10 per cent. were replaced each year as defective or worn out, including those which broke while running.

MILEAGE of CRANK AXLES which BROKE WHILE RUNNING.

Year.	Lowest.	Highest.	Average.	Number of Engines.	Percentage upon Total Stock.
	Miles.	Miles.	Miles.		
1868	70,167	260,000	154,266	637	2·82
1869	29,000	269,000	134,000	716	3·21
1870	49,000	320,000	148,500	775	4·51
1871	31,800	287,000	160,000	909	3·96
1872	53,000	304,500	158,000	995	3·31
1873	55,000	364,000	163,000	1,034	4·15

The average mileage of crank axles of the best Yorkshire iron, under three classes of engines, was:—

Class.	Cylinders.	Diameter of Wheels.	Miles.
	Inches. Inches.	Ft. Ins.	
Single driving wheel passenger engines . .	16½ × 22	6 6	163,221
Four-wheel coupled passenger engines . .	16½ × 22	6 0	167,370
Six-wheel coupled goods engines	16½ × 24	5 0	195,534

the average of the three classes being 175,377.

The whole of these crank axles had inside and outside bearings (double frames).

On the London, Chatham, and Dover railway nearly the whole of the engines had crucible cast-steel crank axles, their average mileage up to the present time being:—

	Miles.
Four-wheeled coupled passenger .	169,117 (41,548 to 287,963)
Six „ „ goods . . .	103,745 (5,994 to 162,788)
Four „ „ tank . . .	150,366 (26,533 to 256,502)

Two axles broke while running under four-wheel coupled passenger engines, their average mileage being 109,558; they had not been included in the above figures.

Mr. D. DRUMMOND furnished, through the Secretary, a tabular statement of the expenditure in the locomotive, carriage, and wagon departments of various railways, for the half-year ending the 31st of July, 1876, as follows (see next page).

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Name of Railways.	Locomotive Department.								
	Number of Engines.	Train Miles run.	Train Miles per Engine.	Total Cost of Working.	Cost per Train Mile.	Total Cost of Repairs.	Cost of Repairs per Engine.		Cost per Train Mile.
				£.	d.	£.	£. s.	d.	d.
London and North-Western . . .	2,032	15,825,949	7,788	427,711	6·56	196,821	96 17	2	2·99
Great Western. .	1,461	12,590,190	8,618	267,997	5·11	173,308	118 12	6	3·30
North Eastern. .	1,364	10,754,242	7,883	333,854	7·45	201,858	147 19	4	4·52
Midland . . .	1,261	11,034,666	8,751	311,218	6·77	138,754	110 0	8	3·01
Lancashire and Yorkshire . .	673	5,601,270	8,323	164,017	7·03	93,841	139 8	9	4·02
Great Northern .	566	5,602,629	9,899	145,616	6·24	64,336	113 13	4	2·74
Manchester, Sheffield, and Lincolnshire	388	2,477,550	6,387	63,504	6·15	22,527	58 1	2	2·18
London and South-Western . . .	348	4,110,071	11,810	102,415	5·98	48,664	139 16	9	2·84
London, Brighton, and South Coast.	278	2,946,739	10,599	87,409	7·12	29,334	105 10	5	2·39
South-Eastern . .	258	2,346,238	9,094	78,110	7·99	29,170	113 1	3	2·98
London, Chatham, and Dover . .	148	1,355,330	9,158	45,748	8·10	24,205	163 11	1	4·28
North Staffordshire	123	819,877	6,666	24,702	7·23	16,503	134 3	5	4·83
Great Eastern . .	495	4,997,328	10,096	140,629	6·75	58,899	118 19	9	2·82
Dublin, Wicklow, and Wexford .	45	446,390	9,920	8,833	4·75	3,932	87 7	11	2·11
Midland Great Western . . .	98	713,278	7,279	16,700	5·62	9,270	94 12	1	3·11
North British . .	453	4,145,900	9,152	89,884	5·20	53,609	118 6	10	3·10
Caledonian. . .	638	5,355,068	8,398	120,649	5·41	61,503	96 8	0	2·76
Glasgow and South-Western . . .	250	1,968,185	7,873	42,626	5·19	22,673	90 14	2	2·77
Great North of Scotland . . .	56	489,055	8,733	9,387	4·61	4,772	85 4	3	2·34
Highland . . .	67	658,409	9,827	14,832	5·41	7,128	106 8	1	2·59

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Carriage Department.						Wagon Department.							
Number of Carriages.	Total Cost of Repairs.	Cost per Vehicle.			Cost per Train Mile.	Number of Wagons.	Total Cost of Repairs.	Cost per Vehicle.			Cost per Train Mile.	Total Cost of Expenditure.	Total Cost per Train Mile.
	£.	£.	s.	d.	d.		£.	£.	s.	d.	d.	£.	d.
4,885	74,971	15	6	10	1·13	41,651	79,744	1	18	3	1·21	779,248	11·89
4,097	60,241	14	14	1	1·15	32,160	71,386	2	4	5	1·36	572,933	10·92
2,577	53,848	20	17	11	1·20	76,464	175,434	2	5	10	3·90	764,994	17·07
3,343	50,007	14	19	2	1·08	31,156	67,321	2	3	2	1·48	567,301	12·34
2,143	65,138	30	7	11	2·79	18,328	49,364	2	13	10	2·11	372,361	15·95
1,728	23,328	13	10	0	1·00	15,299	30,098	1	19	4	1·30	263,380	11·28
713	10,151	14	4	8	0·98	10,629	25,215	2	7	5	2·45	121,398	11·76
2,133	25,069	11	15	1	1·46	5,927	18,891	3	3	9	1·10	195,040	11·38
1,954	20,264	10	7	5	1·65	6,974	6,908	0	19	9	0·56	143,916	11·72
1,866	22,587	12	2	1	2·31	3,851	9,826	2	11	1	1·01	139,695	14·29
786	11,471	14	11	11	2·03	1,259	4,148	3	5	11	0·74	85,574	15·15
288	3,998	13	17	8	1·17	5,068	13,745	2	14	3	4·02	58,949	17·25
1,958	23,056	11	15	6	1·11	10,685	30,240	2	16	7	1·45	252,825	12·13
176	3,051	17	6	9	1·64	557	1,498	2	13	8	0·81	17,316	9·31
260	3,234	12	8	10	1·09	1,830	6,883	3	15	3	2·32	36,089	12·14
1,579	12,240	7	15	0	0·71	23,556	48,001	2	0	9	2·78	203,735	11·79
1,533	15,192	9	18	2	0·68	34,713	55,621	1	12	2	2·49	252,966	11·34
682	6,356	9	6	5	0·77	10,478	25,887	2	9	2	3·16	97,543	11·89
261	1,669	6	7	11	0·82	2,313	5,933	2	11	3	2·91	21,762	10·68
241	2,819	11	13	11	1·02	2,260	4,460	1	19	6	1·63	29,241	10·65

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Mr. JOHN HEAD asked if the item of sundries included establishment and shop charges; and whether, in calculating the cost of the engines, the Author had included the 5 per cent. upon the large outlay generally made for tools, buildings, &c.?

Sir JOHN HAWKSHAW said he should have been glad to ask Mr. Kirtley, had he been present, whether the iron tubes to which he had referred were connected with copper fire-boxes. He himself began the use of iron tubes as far back as 1834–5, and, but for the difficulty experienced with the iron fire-boxes, he should have been using them to the present day. It might be interesting to those who were connected with locomotives to know that, in the United States, brass tubes were not now used; nor were copper fire-boxes employed. All the fire-boxes in the United States were of steel, and the tubes were of iron. From what he had seen and heard in America he thought it worth while for locomotive makers and engineers to consider whether steel fire-boxes and iron tubes would not be cheaper and better than copper fire-boxes and brass tubes. His own impression was that the change would be an improvement. Of course the steel plates must be of equal quality; and with such plates he believed a better result would be obtained at a less cost.

Mr. MCDONNELL, in reply, said he thought the question of steel fire-boxes and iron tubes should be considered an open one. His own experience in the matter had not been large, but as far as it went, he preferred copper fire-boxes. He had tried fire-boxes of steel made at Pittsburg, and they did not last as long or pay as well as copper. The engines had come in for repairs more on account of fire-boxes, than on account of tires; and he did not think that was a satisfactory result. Perhaps, however, he had been a little nervous about using the steel as thin as it was employed in America: possibly they might have lasted better if they had been thinner. He had been much struck by the bad results on the Reading and Philadelphia railroad by the use of copper fire-boxes and brass tubes. He thought that could only be explained by the company having accidentally got brass tubes of excessively bad quality, and not continuing the experiment sufficiently long. The steel fire-boxes on the Great Southern and Western might not have been a fair average, and he would not, therefore, condemn such fire-boxes simply from his own experience. With regard to the thickness of iron tires, he had found great difficulty in obtaining the exact measurement, but he believed it was 2½ inches. The steel tires, the mileage of which had been given, were 2½ inches, those now used were 3 inches thick. The "sundries" were made up of a large number of small items, the particulars of

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which were given in Table 10. With respect to train mileage, it was, no doubt, unfortunate that there was not a more distinct unit for comparison. He had taken it because it was the only thing given in the half-yearly reports that he could adopt as a unit. In some cases the engine mileage greatly exceeded the train mileage. In the instance mentioned by Sir John Hawkshaw —that of the Lancashire and Yorkshire railway—the engine mileage much exceeded the train mileage; but that was rarely the case on the lines whose accounts he had analysed. On most English lines the train and engine mileage did not greatly differ, the proportion being about 100 to 125. On the Lancashire and Yorkshire the proportion was 100 to 177. He thought Mr. Price Williams had somewhat misunderstood what he had said with regard to the Midland and the Great Northern. He had simply stated that, as far as figures were concerned, it would not be correct to conclude that the Midland was worked more economically than the Great Northern, because the increase of their engine stock was much larger, and the figures had been taken without reference to such increase. It might be that there was greater economy on the Midland than on the Great Northern; but the figures did not prove it. Unfortunately there was a looseness about the meaning of the word "renewals," as shown by what Mr. Armstrong had said, and he had endeavoured as much as possible to guard against any misconception. He had given nothing as renewals where the engine was not entirely renewed, except in three cases where the wheels were not renewed. It was, of course, difficult to draw the line between renewals and repairs, especially when continuing the same class of engine, but upon his own line there was no great difficulty in that respect.

The Great Western appeared to have done a great deal; but, as far as their published accounts were concerned, the Great Northern seemed to have done more, without any increase in the cost of repairs. In 1868 the Great Northern had four hundred and ninety-three engines, and since that time they had rebuilt three hundred and twenty-eight, or 66 per cent. The Great Western had eight hundred and sixty-seven engines at the same time, and had rebuilt four hundred and twenty-six, or 49 per cent. He could not tell whether the Great Northern had included in the rebuilding the engines into which they had simply put new boilers. It was unfortunate that the Midland, the London and North-Western, and other large companies had not published similar information. He thought that Mr. Price Williams's plan of taking the cost per engine, instead of the cost per train mile, was

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not a good one. The cost per engine varied enormously on different lines, where the cost per train mile did not vary seriously. In 1876 the London and North-Western Company had spent an average of £182 per engine; while the London and South-Western, with a much smaller number of engines for the amount of traffic, had spent £329 per engine. The Great Southern and Western had spent £223 per engine, which he thought too great a variation to be taken as a fair measure. As to the large mileage of tubes, he had not mentioned it without a great deal of careful investigation as to whether the tubes were those that had been originally put in or not; but he had found that there was no question about it. The tubes were No. 10 wire gauge at the fire-box end, and No. 11 at the smoke-box end. None of them had been pieced, and a very small percentage had been renewed. He had built some twenty engines; they had brass tubes, and had all run upwards of 200,000 miles, and still had the same tubes that were originally put in. The water was fairly good, with an average hardness of about 20°; there was nothing deleterious in it, and nothing exceptional in its quality. He did not think that it differed in any way from that used by railways in the south of England. A thick tube lasted much longer than a thin one. It was something like a tire: a certain amount was scrap and all the rest useful material, and the thicker the useful material was the longer it would last. It would be seen, by reference to the note, page 13, that there were ten engines which required as many brass tubes for repairs as all the rest of the engines put together. Those were all thin tubes. The best water was used by these engines; so good that he was even able to run engines for three weeks without having them washed out. He was sorry that he could not tell the exact wire gauge. With respect to the designs of the engines, he thought that Mr. Adams must have looked through the drawings of some of the old engines, which certainly did not make use of the Irish gauge in a proper way. The standard engines of which diagrams were given had journals 8½ inches long by 7 inches in diameter. The big end journal was 4½ by 7 inches, about ½ inch larger than the narrow gauge. The throw of the crank next the frame was 4⅜ inches, and next the eccentric sheaves 5 inches; the distance between the valve faces was 7 inches. The large bearings and the extra strength of the throws of the crank axle probably explained, to a certain extent, the good mileage he had always obtained from crank axles. It also partially explained the large mileage between repairs—large considering the roughness of the permanent way. The explanation

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given by Mr. Armstrong as to the difference in the form of keeping accounts was an obvious one. He had looked into the matter himself, and he could hardly think that the difference could be explained as a simple matter of account; for it was not simply between the Great Southern and the Great Western, but between the Great Western and the London and North-Western, the Great Northern, and Midland, and other railway companies which manufactured wheels, cranks and the like. He found the difference to be 0·41*d.*, which upon the Great Western mileage from 1868 to 1876 amounted to £249,099. That was a large sum, and it would have bought all the wheels and axles at the high price which he paid for them, for all the engines that the Great Western had in 1868. He did not think that the steeper gradients of the Great Western had much to do in the matter. Although a steep gradient might affect the consumption of coal, and perhaps some other things, such as tires, included in the repairs, it did not seriously affect the general question of repairs. Mr. Armstrong thought that he was wrong in separating the repairs from the general running expenses; but considering the difference in the cost of the various kinds of materials, and the different circumstances of the railways, to introduce another question, that of coal, would unnecessarily complicate the matter. The question of coal was not only one of difference of cost, but also of difference of quality, which it was very difficult to eliminate. The Glasgow and South-Western Company, for example, paid 6*s.* 0¾*d.* per ton for coal, and burned 42 lbs. per engine mile. The Great Western paid nearly 9*s.* per ton, and burned 34½ lbs. per engine mile. The coals were not only different in price, but in quality; and to introduce such figures would be to make the matter more complicated than it was already. The complication would be still greater in his own case, because he paid 20*s.* per ton for coal and only burned 27 lbs. per engine mile. He burned nearly the same quality of coal as the Great Western, and paid more than double the price. He thought it was much better to take nothing whatever except simple repairs and renewals. As to the engines themselves, the real question was whether a cheap engine was the most economical in the long run. The Great Western built engines with iron tubes, iron axles, and probably with Bessemer steel tires. They were, no doubt, cheaper than engines with brass tubes, cast-steel axles and cast-steel tires; but the question was whether such engines, taking into consideration the first cost and the repairs for twelve or fourteen years, were the cheapest. He had given the cost of a rather expensive engine, and he should like to see a similar table for a

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cheaper class of engine before deciding upon the point as to which was in the end the more economical. He thought that Mr. Armstrong had entered a little more elaborately into the defence of the Great Western Company than was necessary. They had changed the broad-gauge stock for a narrow-gauge stock, and had rebuilt a great deal. Adding the wages and material together, the line was no more expensive than other railways in England. The cost on the North-Eastern was exceedingly high, and, unlike the Lancashire and Yorkshire, it could not be said that the train mileage and the engine mileage differed sufficiently to account for the excess. The North-Eastern spent about 4*d.* per train mile upon the repair of engines, whereas the amount spent by the other companies was about 3¼*d.*, a difference that appeared to him to require some explanation. There must always be a difference of opinion as to the best and most economical materials to be used in the construction and repairs of locomotives, as the destruction of particular parts would vary on different lines of railway. In his opinion the best way to estimate the cost of various kinds of materials, with a view to ascertain the most economical, was by the train mile or engine mile for a series of years in a form similar to that of Tables Nos. 6 and 7. No real information could be obtained from statements that copper fire-boxes lasted from three to five years, or that brass tubes had run from 55,000 to 309,000 miles. Much valuable information was often practically useless on account of the indefinite way in which it was given.

Mr. STEPHENSON, President, said there could be no doubt that the Paper and the tables prepared by Mr. McDonnell would be of great service, especially to the younger members of the Institution. He agreed with what Sir John Hawkshaw had said in regard to renewals, and also in the remarks of Mr. Woods. But their observations only referred to small matters affecting the life of a locomotive engine. He believed many engines had been killed earlier than they ought to have been, especially during the last few years, because the traffic had increased to such an extent that the companies could not maintain the engine power to keep pace with that increase. Engines had been running when they ought to have been in the shops. They came in, their boilers were blown out, they were filled with cold water almost immediately, and every locomotive engineer knew what that meant. Then there was the question of the water itself. On some railways it was bad, on others indifferent, and on others scarcely fit to use at all. The water question was a matter which had an important effect, not only upon locomotives, but upon marine boilers. It was evident

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from the figures in the tables that no two lines of railway could be compared in regard to the cost of renewals. There was also the question of locality to be taken into consideration, as having a remarkable effect upon repairs and renewals. He was anxious to know what the public was paying for the high speeds of the fast express trains. No one could tell the amount of damage done by such trains to the general stock of a company, the permanent way, and every class of machinery. They also involved an immense amount of extra labour at stations, shunting, porterage, signalling, and the like, so as to keep the line free. With regard to the question, whether interest on capital, on shops and machinery, was charged by the railway companies against cost of construction, from all the information he had been able to obtain as to the mode in which the cost of locomotives constructed by railway companies was ascertained, he believed this portion of the capital was mixed up in a chaos with all the other stocks of the company. With reference to the high charge for renewals on the North-Eastern, it should be stated that a year or two ago that company had scarcely a spare engine. The engines were at work night and day, and that circumstance must have added greatly to the cost of renewals, as many engines were compelled to work after ordinary repairs were necessary.

January 23, 1877.

GEORGE ROBERT STEPHENSON, President,
in the Chair.

The discussion upon the Paper, No. 1,469, "The Repairs and Renewals of Locomotives," by Mr. ALEXANDER MCDONNELL, occupied the entire evening.

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ACTION OF SEA-WATER ON COPPER SHEATHING.

Dr. PERCY exhibited a piece of copper sheathing which had been put on her Majesty's ship "Argonaut" in 1790, and taken off in 1830. There were two holes in the piece, through which passed nails for the attachment of the copper to the ship, and across these holes there were lines of the metal in relief; the Admiralty arrow-mark was also in relief.

Mr. Weston, from whom Dr. Percy had received the specimen in 1873, and who for many years had charge of the Chemical Department at Portsmouth Dockyard, communicated the following particulars relating to it:—"I found two such specimens preserved, one at Portsmouth and the other at Chatham, and both had the lines in relief proceeding from nail-hole to nail-hole. Over one is the arrow-mark included in the piece which I cut off for you. Towards elucidating the cause of these lines, I can only state the following fact, that formerly it was customary to mark the position of the nail-holes by lines drawn upon the copper with a steel tool called a 'scribe.' The arrow-mark is not the usual stamp-mark, and may have been made in a similar manner; but against this supposition it may be said that no other specimen shows the same result. I find none, however, of so early a date, except the sheathing of the 'Royal George.' In the recent cases which have come under my notice, a section of each nail-hole exhibits a considerable concavity, whereas the parts in the specimen sent which were covered by the heads of the nails are in relief."

Dr. Percy observed on this, that where the "scribe" was drawn across the copper, there must have been compression of the metal to a degree probably sufficient to produce actual polish; and this action seemed to have protected the copper from corrosion by the sea-water. It could hardly be imagined that the protection was due to traces of steel left upon the surface by the "scribe," as they must have been infinitesimally minute. The question of what he had termed the "corrosive susceptibility" of copper to sea-water was one of great practical importance and of high scientific interest. On an early day he proposed to forward other illustrations of a remarkable action of sea-water on Muntz-metal bolts.

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January 30, 1877.

GEORGE ROBERT STEPHENSON, President,
in the Chair.

No. 1,504.—"On the Combustion of Refuse Vegetable Substances, such as Straw, Reeds, Cotton Stalks, Brushwood, Megass, &c., under Steam Boilers." By JOHN HEAD, Assoc. Inst. C.E.

THIS subject is to some extent novel, partly because the opportunity has hitherto rarely existed for burning refuse vegetable substances as fuel under steam boilers, and partly on account of the preconceived, but natural, idea that the generation of steam can only be produced by heat evolved from coal or wood. Besides the knowledge possessed by almost every workman of the properties of coal and wood, these materials have been subjected to the most crucial tests with regard to their evaporative duty, by which the user of steam power is able to calculate the prime cost of working an engine, with more accuracy than if an attempt were made to use a fuel which has hitherto been considered as a refuse, capable of being ignited, it is true, but incapable of supplying sufficient heat to generate steam in a boiler.

In the neighbourhood of cities, or in countries where the cultivation of cereals does not produce a surplus over the demand for straw for agricultural and manufacturing purposes, it is evident that it would be useless to attempt to use straw as fuel, its market value being invariably in excess of that of coal or wood. Again, in countries where coal and wood are abundant and cheap, it would be absurd to advocate the use of substances for fuel which are inferior to coal in calorific properties, and are more difficult to obtain and to transport.

But these conditions do not exist in all countries. On the vast steppes of Hungary and South Russia, a traveller may journey for hours without seeing a tree sufficiently large to be used as firewood; coal can only be obtained at a high cost, and, until the application of straw and other vegetable substances as fuel became known, sheep-dung was the only substance which could be burnt under steam boilers with economy. The want of steam power is equally felt in other agricultural districts besides those mentioned. In India the dried leaves of fibrous plants, the scrub

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or brushwood, and the stalks of the cotton plant, supply an excellent substitute for coal under boilers properly constructed. In Egypt, the cotton plants are pulled up after having attained a certain growth, and the stalks, which are about ½ inch in diameter and 4 to 5 feet in length, contain all the calorific properties of good wood, and burn equally well if properly inserted into the furnace. In the large wheat-growing districts of the Maremma and the Puglia—in the West and South of Italy—wood and coal are scarce, and as the grain requires to be threshed shortly after harvest, on account of the nature of the climate, the farmer would gladly avail himself of steam power, provided straw, which is always at hand and in superfluous abundance, could be used. In South America, New Zealand, and the extensive prairies of the River Plate, Chili, and Mexico, the universal demand of the farmers is for steam machinery which can be worked with indigenous fuel; and the time may come, ere long, when the land in these countries shall be ploughed, the crops harvested and threshed, and the grain ground into flour, by steam engines fed with the straw, brushwood, and vegetable refuse grown on the spot. Indeed, the want of means to utilise many species of combustible material as fuel has hitherto been the only drawback to the almost universal employment of steam in agriculture.

About ten or twelve years ago, the price of all descriptions of fuel increased not only in South Russia, and the corn-growing districts of the East, but in many other parts of the world, on account of the demand for all kinds of wood for the construction of railways, and for buildings in the large cities and towns throughout the Continent of Europe, where coal is not indigenous and only to be obtained at a high price. This naturally augmented the demand for wood for heating and culinary purposes. In consequence, the market value of wood became so high in the agricultural districts, that the cost of the only fuel for steam boilers, hitherto obtainable at a reasonable price, was materially increased.

This state of affairs compelled the users of steam power to consider the applicability of other fuel than coal and wood. About the year 1872 the Author and the late Mr. Schemioth, a Russian engineer, made several experiments with a locomotive boiler adapted to a portable engine, in order to perfect the combustion of straw and other vegetable refuse. It was decided to inject the fuel automatically into the furnace, by an apparatus not unlike the feed motion of a chaff-cutter. In the construction of the boilers which resulted from these experiments, the necessity of adapting them to

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the consumption of almost every known species of fuel was constantly kept in view, and the engines manufactured on Head and Schemioth's system will burn not only the refuse vegetable substances already enumerated, but also coal and wood, peat of all kinds, sawdust, chips, and other similar materials. In these latter cases, the mechanical feeding apparatus is removed, and alterations are made in the fire-box.

There is some difficulty in ascertaining the exact amount of straw, or other vegetable substance, consumed per HP. per hour by a high-pressure engine, from the fact that vegetable substances, like straw, vary in their calorific properties. Many experiments have, however, demonstrated that the combustion of from 3·25 lbs. to 3·75 lbs. of average dry wheat straw will evaporate the same amount of water in the same time as 1 lb. of good coal in the most modern boiler. The amount of straw grown per acre varies very much. In England the average may be taken at about 30 cwt. per acre, for wheat straw, or say 3,300 lbs. per acre, worth to the farmer about 30*s.* per ton on the estate; consequently the value of produce per acre would be about 44*s.* Then, if the value of 1 ton of coal, at the farm in England, be taken at about 20*s.*, and if the proportion of 3·5 lbs. of straw to 1 lb. of coal be admitted, the following conclusion will be arrived at:—3,300 lbs. of straw, costing about 44*s.*, are equivalent to 943 lbs. of coal, costing about 8*s.* 6*d.* From this comparison the commercial value of straw in proportion to coal is ascertained to be about 1 to 5: that is to say, it would cost in England five times more money to use straw for steam boilers than coal. It will thus be evident, that straw cannot be used with advantage as fuel for agricultural operations in England, and generally this is the case in the western and northern countries of Europe.

These calculations present, however, an entirely different aspect in the large corn-growing districts of Russia and the East, India, South America, and some of the colonies, where the minimum cost of coal delivered at the farm is at least from £3 to £4 per ton, and where straw is of merely nominal value. The large farmers in these districts cultivate such enormous areas of cereal crops, that an immense quantity of straw always remains, after harvesting the crops, over and above what is required for manure and for the farmyard. For instance, if in Russia, Hungary, and the Danubian Principalities, the cost of coal be taken at the minimum price of 60*s.* per ton, and of straw at 5*s.* per ton (which is generally much above its real value), and the same proportion be allowed as in the previous calculation, viz. that 3·5 lbs. of straw are

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equal in their calorific effect to 1 lb. of coal, and also that the produce of an acre in these countries is the same as it is in England (although in reality it is somewhat less), then the comparison between the produce of an acre of straw, and its equivalent weight in coal will be: 3,300 lbs. of straw, costing about 7*s.*, are equal to 943 lbs. of coal, costing 25*s.* 6*d.* These figures, therefore, show that the commercial value of straw in proportion to coal, when used as fuel in Russia and the East, India, South America, &c., is as 3·6 to 1; or that it costs more than three and a half times as much to use coal under steam boilers as straw. Taking an agricultural engine of 12 effective HP., and the consumption of straw at 20 lbs. per HP. per hour, the produce of straw per acre will enable the engine to work from twelve to eighteen hours.

The following table shows the chemical composition of various materials, in their ordinary air-dried condition, now used as fuel under steam boilers:—

——	Carbon.	Hydrogen.	Nitrogen.	Oxygen.	Sulphur.	Ash.	Water.
Coal, coking, Newcastle .	80·33	5·72	2·03	7·78	0·74	2·05	1·35
„ „ South Wales	82·32	6·09	4·54	1·48	0·76	3·99	0·82
„ non-coking „ „	88·62	4·40	1·23	3·23	0·54	1·19	0·79
„ „ South Staffordshire . . .	74·54	4·95	1·01	8·50	1·19	1·95	7·86
Lignite, Bohemia . . .	58·29	4·68	0·80	17·62	0·71	5·30	12·60
Peat, Ireland	50·13	5·06	0·76	26·85	..	2·83	14·31
Wood, oak	41·02	5·13	0·86	35·11	..	1·83	16·05
„ pine	41·99	5·26	0·75	35·98	..	0·63	15·39
Straw, wheat	35·86	5·01	0·45	37·68	..	5·00	16·00
„ barley	36·27	5·07	0·40	38·26	..	4·50	15·50

No chemical analyses of the composition of megass and cotton stalks have as yet been made.

The average calorific effect found in practice to exist in coal and other products, when used as fuel, is as follows:—

1 lb. of good coal . . . . .
2 lbs. of dry peat . . . . .
2·25 lbs. to 2·30 lbs. of dry wood .
2·50 lbs. to 3 lbs. of cotton stalks, brushwood, or megass . . .
3·25 lbs. to 3·75 lbs. of wheaten or barley straw . . . . . } will evaporate 8 lbs. of water in an ordinary tubular boiler.

Having traced the theoretical value of vegetable refuse as a fuel, it will now be necessary to describe some of the means by which straw has been burnt under steam boilers.

Fig. 1, Plate 3, shows the earliest adaptation of a brick furnace

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in a pit to the boiler of an ordinary portable engine for the combustion of straw, as employed in Russia. The pit was about 10 feet square and 7 feet deep, and at one end a small furnace, similar in size and shape to a baker's oven, was built of bricks. This furnace was connected with the fire-box of the engine by an inclined tunnel, or brick flue, enlarged at the top to the sides of the fire-box, and made as tight as possible at the junction between the bricks and the angle-iron ring, by clay or mortar. Air was admitted, in small quantities, into the connecting flue by an opening fitted with a damper. The fire was made on the open hearth without difficulty, and was fed continuously with slight allowances of fuel. The heated gases passed up the flue into the fire-box of the engine, and thence through the tubes into the chimney. The disadvantages of this system were, that it was necessary to have two men to look after the engine, one in the pit and the other on the ground. The heat of the flames passing up the flue into the fire-box attacked the rivets and the ring at the bottom of the fire-box, causing rapid deterioration, besides which a heavy outlay had to be incurred, for the construction of a new pit and flue, whenever the engine was moved from one place to another.

Fig. 2 shows another method, employed chiefly in Hungary and in Wallachia, for burning straw in ordinary portable engines. It differs from the system previously described in the construction of the furnace. A rectangular hole, from 3 feet to 4 feet deep, is dug in the ground. One part of this hole is covered by the fire-box of the engine, and the remainder by slabs of stone, or sheet iron. The engine is elevated, so as to raise the bottom of the fire-box about 2 feet from the ground, and the junction between the bottom of the fire-box and the hole is effected by bricks set in mortar or clay. The straw for feeding the fire is forced in with a fork through a small aperture, about 10 inches or 12 inches square, in the front part of the brick furnace, and about half the fresh fuel overhangs the space left below the fire-box in the pit. Immediately the fresh straw—which has been pushed in through the hole—comes in contact with the hot ashes heaped up in the pit, it bursts into flame, and the heated gases find their way through the tubes into the chimney. The ingress of atmospheric air to the furnace is regulated through the feeding-hole, and also, if necessary, by shifting one of the stone, or iron, plate covers at the end opposite to the engine. This system of building the auxiliary furnace is rather cheaper than that of the other, and is more economical in the consumption of fuel. One man can attend to the engine,

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including stoking; but in this case, as well as in the other, expense is incurred in building a fresh oven upon the removal of the engine from one farmyard to another. In both these systems of firing, it is difficult to keep up steam at a regular pressure with straw which is damp, or mixed with weeds and other foreign substances. In both, too, a careful and attentive workman must be employed for feeding the auxiliary furnaces, as a clear fire can only be kept by supplying the furnace with straw at frequent intervals and in thin layers.

Figs. 3, 4, 5, and 6 show one of the most recent engines for this purpose. It differs from all others in its capability for burning every description of fuel; that is to say, whilst the furnaces of many engines are arranged to burn either coal, wood, or peat with the greatest economy, but are incapable of using any other kind of fuel, the furnace of the boiler of this engine can be so adjusted, that a proper combustion will take place, not only of substances hitherto used as fuel, such as coal, wood, peat, &c., but also of all other vegetable material previously considered worthless for generating heat in steam boilers.

The theory of the invention is that the fuel should be forced, by a continuous mechanical feed, into the furnace in a thin stream in the form of a fan. The fresh fuel is practically held in suspension for a short time, which allows the separate stalks to become immersed in the flames. The long pieces of straw, reeds, or brushwood have the effect of stirring up the half-burnt material in the furnace, and of keeping the whole in motion, besides permitting a free ingress of atmospheric air.

The apparatus designed for feeding the straw, reeds, and other vegetable refuse into the fire-box, consists of a pair of serrated rollers, which, in the case of engines of from 6 HP. to 20 HP., are about 5 inches in diameter and 18 inches long, placed at a minimum distance of $\frac{1}{4}$ inch apart. The upper roller is, however, capable of rising, so that the distance between the rollers can be increased to $1\frac{1}{4}$ inch, and thus allow for different thicknesses of material. The under roller is set in motion by a strap from the crank-shaft of the engine, and makes about forty-five revolutions per minute; when the engine is getting up steam, this roller is turned by hand with an ordinary crank. The upper roller moves at the same speed, and is connected with the under one by wheels with long teeth. The rollers are set in a cast-iron frame, which is fixed to the boiler by a hinge. To the front of this frame there is attached a trough, for holding the supply of vegetable fuel to be fed into the furnace. Above the rollers there are three

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flaps, which enable the stoker to look into the fire-box, and also to use a poker if necessary.

To test the practical value of this apparatus, and to arrive at the best proportions of heating surface and the best position for the automatic feeding apparatus, three engines, each of about 10 nominal HP., were constructed by Messrs. Ransomes, Sims, and Head. In two of these, the amount of tube and grate surface most suitable for vegetable refuse was determined. The following table shows the comparison between the grate area, the fire-box surface, and the tube surface, for coal and for vegetable products respectively, per nominal HP.:—

	Coal. Sq. ft.	Vegetable refuse. Sq. ft.
Area of grate surface	0·62	0·93
„ fire-box „	2·80	4·30
„ tube „	15·24	21·82
Total heating surface . . .	18·04	26·12

It is usual to have a deeper fire-box when consuming straw and other similar products than is required for coal. The experiments also demonstrated, that tubes of 2¼ inches in diameter give a better result in the consumption of vegetable products than tubes of 2¾ or 3 inches in diameter, the size usually employed in portable-engine boilers adapted for coal.

After having ascertained the best approximate heating surface for these boilers, two difficulties remained to be overcome. One consisted in finding out the exact point at which to inject the vegetable fuel into the furnace, and the other in preventing the deposit of silica and slag on the grate-bars. The first problem was solved by the construction of a third locomotive boiler, with additional heating surface, as specified in the foregoing table. Instead of a fixed hole for feeding the furnace with fuel, a long rectangular aperture was made, in front of the boiler, ranging from within a few inches of the crown down to the bottom of the fire-box. In front of this aperture the self-acting feeding apparatus was fixed at different levels, the results of the experiments being registered every day. It was found that when the fuel was injected into the fire between 5 and 6 inches from the top of the grate-bars, the greatest economy was obtained, there being a more rapid combustion with less smoke than at any other position. At this height the half-burnt and the fresh fuel were kept continually stirred by the fresh fuel coming into the furnace through the rollers. The experiments also clearly demonstrated,

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that if damp straw is fed on to the top of the fire, as when stoking wood or coal, the fire is almost quenched, and the amount of smoke evolved increases largely; but if the fuel is forced into the hottest part of the fire, and is supplied alternately on the right and the left-hand sides of the fire-box, so that the fire on one side is always clear and bright, combustion can be maintained with vegetable refuse containing more than the natural amount of moisture.

The deposit of silica on the bars varies according to the nature of the vegetable fuel, the proportion of silica being greater in straw and vegetable matter grown in hot than in cold countries. The silica is not deposited in hard masses on the bars, so as to prevent the proper ingress of atmospheric air, until after the engine has been at work for several hours. It was found that if an apparatus could be made to act before it became glomerated, the space between the bars could be kept as free and open as when burning coal or wood. Many experiments were tried with variously shaped grate-bars, with self-acting bars like Juckes', and with rotary prickers turned by a handle outside the boiler; but the simple apparatus now in use has proved entirely efficacious. It consists of a rake with five or six teeth, according to the width of the fire-box, the top of these teeth projecting about 2 inches above the grate-bars. One end of this pricker is attached to a handle, which projects outside the ash-pan, and can be worked by the stoker, and the whole apparatus slides backwards and forwards upon two wrought-iron guides underneath the grate-bars. When the apparatus is used, it is drawn from the back to the front of the fire-box along one side of the grate-bars. It is then shifted to the other side of the 4-inch space, and travels from the front to the back of the fire-box alongside the other side of the space, and thus cuts away all the deposit of silica, which falls into the ash-pan.

There was also a slight deposit of silica and slag in some of the tubes, especially in the two lower rows, which impeded a proper generation of steam. To obviate this, and to prevent the necessity for stopping the engine and cleaning the tubes, a steam jet, consisting of a wrought-iron pipe with a brass rose at one end (Fig. 5), was attached, with an india-rubber pipe, to a cock in front of the boiler. When the tubes were furred this apparatus was inserted through the flaps in front of the boiler, and the whole of the silicious deposit was blown through the tubes into the smoke-box.

Some difficulty was experienced in dealing with the light ashes,

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which were deposited in large quantities in the ash-pan, when the engine was at work in the steppes of Russia and Hungary, where the strong winds have a tendency to blow the hot ashes out of the ash-pan. In order to keep the ashes damp, a pipe, connected with the feed-pump, was carried from the pump along the front of the fire-box. This pipe was pierced with holes at different angles, which ejected water on to all parts of the ash-pan. The arrangement was found most effectual, not only for damping the ashes, but also for keeping the fire-bars cool. The combustion of the fire in these boilers is so perfect, that but few sparks escape from the chimney. Although in some cases the funnel-shaped American spark-catchers have been fixed to the engines, yet the ordinary spark-catcher used for wood has proved amply sufficient for all practical purposes. It has also been found in practice, that the sparks occasionally emitted from straw-burning engines are not so dangerous, or so likely to ignite anything upon which they may fall, as the sparks from the chimneys of wood-burning engines.

In those cases where it may be necessary to burn coal, wood, peat, or sawdust, in the boilers which have been described, the mechanical feeding apparatus is removed, and in its place an ordinary fire-door is substituted. Instead of only four or five grate-bars, placed at intervals of about 4 inches apart, the full number of grate-bars is inserted in the fire-box, with spaces of about $\frac{3}{8}$ inch to $\frac{5}{8}$ inch between the bars. The sliding pricker is also removed.

Steam engines were constructed for burning peat, sawdust, &c., before straw was used as fuel under steam boilers, but the proportion of carbon being smaller, and that of water larger, in peat than in coal, it became necessary to increase the grate area and heating surface, in order to compensate for the difference of calorific effect between equal weights of peat and coal. When sawdust, mixed with a small proportion of slack coal, or with chips of wood, is burned under the boiler—which often happens with engines used for driving saw-mills, or wood-working machinery—an amount of grate surface equal to nearly 1 square foot per nominal HP. is required, so as to obtain a thin fire spread over a large area.

As the proportion of heating surface necessary for burning vegetable refuse is about the same as that required for peat, sawdust, &c., it follows that the improved boilers can be employed in a modified form for burning other substances, although their chief adaptation is for the combustion of straw, reeds, brushwood, cotton stalks, and megass. Should these boilers be used for coal, a similar change is introduced in the general arrangement of the fire-box as

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for peat, but the proportion of grate surface to the amount of water required to be evaporated being much too large for the economical consumption of coal, it is usually diminished by inserting a row of fire-bricks at the back and front of the grate-bars, so as to reduce the area of the grate to 0·7 square foot per nominal HP.

Many experiments have been made with these engines to arrive at data respecting the consumption of straw; but it is almost impossible to give such accurate figures as those tabulated for coal, owing to the variety in the straw grown in different countries and soils—some producing results below those already specified and others exceeding them. It is well known that straw imbibes moisture rapidly, and the state of the weather has much to do with the quantity of vegetable fuel consumed by an ordinary tubular boiler. Copies of reports of the earlier experiments conducted before scientific men, both in England and abroad, are given in Appendix A.[1] Later experiments at the Orwell Works, Ipswich, on the 10th and the 19th of August, 1875, in the open air and with ordinary wheat straw, show the average quantity of straw consumed per HP. per hour. It may be stated that the time required to get up steam with straw and other similar vegetable products did not exceed from forty-five to sixty minutes, according to the quality and condition of the fuel, or about the same as is required when wood is employed.

With a single-cylinder portable engine of 10 HP., the diameter of the cylinder being 10 inches, with a length of stroke of 13 inches, the pressure of the steam being 76 lbs., cut off at about $\frac{1}{2}$, and the revolutions being 140 per minute, the straw consumed was $4\frac{1}{2}$ cwt. in one hour and ten minutes, the load on the break being 22·59 HP. The consumption of straw per HP. per hour was 19·11 lbs., which, taking 6 lbs. as the average consumption by this engine of coal per HP. per hour, gives the proportion of the consumption of coal to straw as 1 to 3·18.

With a single-cylinder portable engine of 8 HP., the diameter of the cylinder being $9\frac{3}{8}$ inches, with a length of stroke of 12 inches, the pressure of the steam being 78 lbs., cut off at between $\frac{1}{3}$ and $\frac{1}{2}$, and the revolutions being 140 per minute, the straw con-

[1] It is not thought necessary to print this Appendix, as the Reports in question will be found in the following periodicals:—"The Engineer," May 23, 1873; "Engineering," May 23, 1873, and December 11, 1874; "The Times," August 22, 1873; "Wiener Landwirthschaftliche Zeitung," August 23, 1873; "Journal d'Agriculture pratique," January 1, 1874, and "St. Petersburg Agricultural Gazette," March 22, 1875.—SEC. INST. C.E.

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sumed was 7 cwt. in two hours and twenty minutes, the load on the break being 16·06 HP. The consumption of straw per HP. per hour was 20·92 lbs., which, taking 6 lbs. as the average consumption by this engine of coal per HP. per hour, gives the proportion of the consumption of coal to straw as 1 to 3·48. The fire-box of this engine was fitted with a baffle plate, fixed in front of the tubes in such a manner that the flame and half-consumed straw did not impinge directly on the tube plate.

The accompanying table shows the proportions, &c., of the engines and boilers built upon this system.

GENERAL DIMENSIONS, WEIGHTS, and MEASUREMENTS of PORTABLE ENGINES FITTED with HEAD and SCHEMIOTH'S APPARATUS for BURNING STRAW and other VEGETABLE REFUSE, SUPPLIED with SINGLE SLIDE-VALVE, SINGLE FEED-PUMP, and BRANCH PIPE from EXHAUST for HEATING FEED-WATER. Manufactured by Messrs. Ransomes, Sims, and Head.

—	Nominal HP.	Diameter of Cylinder.	Length of Stroke.	Revolutions per Minute.	Diameter of Fly-wheel.	Width of Fly-wheel.	Number of Tubes.	Diameter of Tubes.	Grate Surface.
		Inches.	Inches.		Feet. Ins.	Inches.		Inches.	Sq. feet.
Single cylinder.	4	6½	11	140	4 3	5	25	2¼	3·720
	6	8¼	12	140	4 5½	6	39	2¼	5·340
	8	9	12	140	4 8	8	46	2¼	7·625
Double cylinder.	10	10	13	140	5 0	9	54	2¼	9·700
	10	7⅞	12	140	5 0	9	54	2¼	9·700
	12	8¼	12	140	5 0	9	57	2¼	11·020
	14	9	12	140	5 0	9	64	2¼	13·150
	16	9	12	140	6 1½	10	71	2¼	13·400
	20	10	13	140	6 1½	10	89	2¼	15·900

—	Nominal HP.	Total Heating Surface.	Extreme Dimensions.						Approximate Weight.	Approximate Consumption of Straw at double the nominal HP.	Approximate Consumption of Water at double the nominal HP.
			Length.		Width over Axles.		Height to top of Fly-wheel.				
		Sq. feet	Feet.	Ins.	Feet.	Ins.	Feet.	Ins.	Cwt.		
Single cylinder.	4	104·48	14	10	6	2	8	0	62	About 20 lbs. per HP. per hour.	About 4½ gallons per HP. per hour.
	6	160·08	15	6	6	4	8	4	90		
	8	205·38	16	9	6	9	9	0	108		
Double cylinder.	10	266·68	18	6	7	0	9	6	138		
	10	266·68	18	6	7	0	9	6	140		
	12	303·94	19	6	7	0	9	8	159		
	14	356·04	20	2	7	3	9	10	170		
	16	415·50	21	3	8	2	10	6	185		
	20	515·00	21	9	8	3	10	6	205		

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Fig. 7 represents an adaptation of Head and Schemioth's apparatus, for burning cotton stalks under a tubular boiler constructed by Messrs. J. and H. Gwynne, for supplying steam to a 12 nominal HP. pumping engine in Egypt. The general arrangement of the apparatus is similar to that before described. It will, however, be perceived that in designing this boiler it has not been thought necessary to allow so much depth between the grate-bars and the crown of the furnace as is usual in locomotive boilers arranged for burning straw. The advantage of the automatic apparatus for injecting the cotton stalks into the furnace is, that it does so with much more regularity than if they were thrown in by hand; besides which, less atmospheric air is admitted above the grate-bars when the fuel is fed in with rollers than through the ordinary fire-door, which must be frequently opened to insert fresh fuel and keep the fire in order. No accurate data have been registered of the performance of this boiler; but an experiment at Cairo, in March 1874, with a portable engine arranged for burning cotton stalks, gave the following results:—

With a single-cylinder portable engine of 10 HP., the diameter of the cylinder being 10 inches, with a length of stroke of 13 inches, the pressure of the steam being 70 lbs., cut off at $\frac{1}{3}$, the revolutions being 140 per minute, the consumption of cotton stalks amounted to 3 cwt. in one hour and two minutes and a half, the load on the break being 18 HP. The consumption of cotton stalks per HP. per hour was 17·92 lbs., which, taking 6 lbs. as the average consumption by this engine of coal per HP. per hour, gives the proportion of the consumption of coal to cotton stalks as 1 to 2·98.

No doubt the refuse of cotton plantations can be largely used as fuel for steam boilers in all districts where cotton is grown, and its only inferiority to the best wood fuel consists in an excess of pyroligneous acid in its composition. Several portable engines for pumping are now at work in Egypt, in which cotton stalks alone are used as fuel, and in which steam is kept up with the greatest regularity. Ultimately it will unquestionably form one of the most important articles of fuel in Egypt, where wood is not indigenous, and coal also has to be imported.

Fig. 8 shows an arrangement of the automatic feed applied for burning megass, or sugar-cane refuse, to the furnace of one of the tubular boilers of His Highness the Khedive's sugar mills in Egypt, constructed by Messrs. Eastons and Anderson. The way in which the apparatus is fixed to the furnace mouth is shown in Plate 4, Fig. 11. The rollers can either be worked by hand or by steam power. It is necessary to have the front of the apparatus

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and the front dead-plate and bars much inclined for this description of fuel, otherwise the rollers would not be able to keep it in proper motion, owing to the pieces of megass being usually rather small, and inclined to agglomerate. By this apparatus a thin stream of fresh megass is continually injected into the furnace, so that the unconsumed fuel gradually forces the half-burnt and burnt megass towards the end, where the combustion is most active. Another advantage is that instead of throwing the fuel on to the top of the fire—which has been proved to be unsatisfactory when using vegetable refuse—the apparatus forces the fresh megass into the centre of the coldest part of the burning mass, thus supplying the fire with fuel without checking the evolution of the gases produced by combustion in the middle and end of the furnace. At Cairo, in March 1874, with the same 10-HP. portable engine which was used for the experiments with cotton stalks, the consumption of megass was found to be 3 cwt. in one hour and eight minutes, the load on the break being 18 HP. The consumption of megass per HP. per hour was 17·77 lbs., which, taking 6 lbs. as the average consumption by this engine of coal per HP. per hour, gives the proportion of the consumption of coal to megass as 1 to 2·96. Where the megass was dried in the sun, it made an excellent fire, and no larger air-space between the grate-bars was necessary than when wood was used as fuel.

In the report by Mr. Bramwell, M. Inst. C.E., and the late Dr. Letheby, on the sugar manufactories in Egypt belonging to His Highness the Khedive, it is stated that 377 lbs. of dry megass (being the produce of 1 ton of cane) are equivalent to 180 lbs. of Welsh coal. If, however, the megass is not perfectly dry, and common coal is used in place of Welsh coal, it is probable the results would more nearly assimilate to those previously given.

Steam Cultivation of the Land (Plate 4).

One of the greatest drawbacks to the more extended use of steam for the cultivation of the soil in the steppes and prairies of corn-growing districts has been the scarcity and high price of coal and wood. It is true that, in some mountainous parts, steam cultivation can never be introduced. Powerful arguments may also be used in favour of ploughing with horses and bullocks, because it is necessary to keep the animals all the year round, and the farmer must always have a herd of bullocks, or a good stud of horses, for the purposes of transport and other farm operations, whether he uses steam or not. Besides, the peasant understands the animals

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and the common ploughs, but has not sufficient education to be intrusted with steam engines, if he is expected to get the maximum amount of work out of the machinery.

Although the best way of cultivating the land in these vast plains, whether by steam or by animal power, will not be solved for many years to come, yet it is evident, that the adoption of steam cultivation and its probable success generally in these outlying districts, depend upon the adaptation of the machinery to the fuel grown upon the estate, which can be obtained at any time and at a moderate cost. The expense of keeping a large quantity of cattle on the estate, whether for ploughing or not, may be compensated for by the largely increased acreage of land which can be brought into cultivation by steam during the few months when it is possible to plough in Russia, Hungary, and similar countries. Capital invested in the steam plough may be made more productive by using the engines, when they are not at work in the field, for driving agricultural machinery, saw-mills, flour-mills, &c. The peasant may learn in time to work the machinery in a satisfactory manner, but nothing can make the steam plough a commercial success, if the owner depends for fuel upon the arrival of coal at some distant port, or upon firewood transported in two or three days from the nearest forest.

For these reasons Messrs. John Fowler and Co. have devoted attention to the construction of the boilers of their steam ploughing engines so as to burn straw, cotton, and maize stalks, or other vegetable refuse. After studying the various systems hitherto invented, Messrs. Fowler decided to construct their boilers with Head and Schemioth's automatic feeding apparatus, supplemented by a means for supplying the vegetable fuel with a fork by hand, through an opening in the fire-box, fitted with a balance door, which closed immediately the fuel was inserted. The grate area and the fire-box and tube surface were largely increased over those of ordinary engines employed for burning coal, as will be seen by the following table :—

	Coal-burning Engines.	Straw-burning Engines.
Area of grate surface. .	6·21 feet	19·14 feet
„ fire-box „ . .	33·00 „	68·00 „
„ tube „ . .	163·27 „	409·60 „

In the ordinary steam ploughing engines, the driving wheels are behind the fire-box, and the steering wheels in front under the smoke-box. The winding drum is in the centre of the engine under the barrel of the boiler. The driver and steersman stand

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on the foot-plate behind the fire-box. In the improved engine designed by Mr. David Greig for burning straw (Figs. 9, 10, and 11), this arrangement is somewhat altered. The large driving wheels are in the forward part of the engine, under the centre of the boiler. The winding drum is under the smoke-box in front of the driving wheels. The steering wheels are attached to a strong wrought-iron frame extending behind the fire-box. This frame, besides carrying the hind axle, serves as the sides of the trough for containing the straw to be passed by the rollers into the furnace. The fuel-feeding rollers extend nearly the whole width of the furnace, and are 3 feet in length and 5 inches in diameter, or nearly twice as long as those used in the ordinary portable engine. The apparatus is in every other respect similar to that already described, and is driven by a pitched chain from the crank-shaft. Above the rollers, a large door, on balance hinges, is fitted into a rectangular aperture in the fire-box. This is used for feeding the furnace with straw by an ordinary pitch-fork, when the engine is not at work, or in case of a break-down of the driving gear of the rollers. By an ingenious arrangement the same table for collecting the straw, prior to its being introduced into the furnace, serves for the automatic feeding rollers, and for operating by hand with a fork. The stoker stands on either the right or the left-hand side of the feeding platform, and the engine-driver stands on a small platform in front of the smoke-box. In these engines the diameter of the cylinder is 10 inches, with a length of stroke of 12 inches, the number of revolutions is 160 per minute, and the average pressure in the boiler is from 100 lbs. to 120 lbs.

The first engines on this principle were made for Count Branicki, of Podolia, Russia, and served to solve the problem, that steam ploughing can be satisfactorily accomplished when straw alone is used as fuel. It was, however, necessary to make some alterations in the general arrangements of the engines, so as to render the manipulation more facile, and also in the distribution of the heating surface in the boilers, so as to produce more perfect combustion. During the year 1876, six similar engines were manufactured for Mr. Butler Johnstone's estate at Timaschew, near Samara, Russia, and they were at work several months, and gave most satisfactory results. In fact, steam ploughing could not have been accomplished under any other circumstances on this vast estate, as no available fuel but straw and brushwood exists in the alluvial plains which stretch for miles along the banks of the Volga. The average consumption of straw per acre ploughed by

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two of these engines, when ploughing 10 inches deep, was about 6 cwt. The average yield of straw per acre in those parts is much less than in England, not exceeding from 2,500 lbs. to 3,000 lbs. per acre. Taking the mean produce per acre at 2,750 lbs., and dividing by 672 lbs., the quantity consumed by the engine in ploughing 1 acre, there results 4·09 as the number of acres which can be cultivated by the straw produced by 1 acre.

If these results are compared with the trials of Fowler's steam ploughs at Wolverhampton, in 1871, where the average consumption of coal required to cultivate 1 acre was 161 lbs., it will be found that 672 divided by 161 = 4·17, or that 1 lb. of coal is equivalent to 4·17 lbs. of straw—a very good result for engines which work intermittently.

Various inventions have been brought out, both in England and in the United States of America, for burning straw under steam boilers, and under certain circumstances these have been attended with success. But the difficulty of obtaining reliable scientific information respecting the performances of these engines has prevented a general description of straw-burning furnaces being included in this Paper. The Author believes, however, that the system described is the only one which will enable the boiler of a steam engine to be fired with every description of combustible matter, including coal and wood, and in which such fuel is supplied to the boiler by mechanical means instead of by manual labour.

Although the burning of vegetable refuse, as well as coal and wood, under steam boilers, is still capable of development, the practical success which, up to the present time, has attended the system has been such, that the steam engine may be extended with advantage to districts where the only fuel is from cereal or other crops grown in the immediate locality, and must encourage the engineer to continue his researches.

It may be argued that, as the means of communication throughout the world are now more rapid and cheap than formerly, coal and wood ought to be everywhere obtainable at a moderate price, but experience has demonstrated the contrary. Wherever civilisation extends its sway, forests are cut down and land is cleared, and each year increases the distance which wood must be conveyed before it arrives at the place where it is to be consumed. Coal mines in new and undeveloped countries are badly worked, and no dependence can be placed upon a regular supply. Transport, whether by land or by water, is always uncertain in time and fluctuating in cost in progressive and semi-civilised countries,

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and these obstacles must operate materially against the use of coal, and to a certain extent of wood, as articles of fuel in all districts outside the limited range of rail or water carriage.

Thus it appears to the Author that as the demand for mechanical appliances increases, so will the difficulties of obtaining the "best" qualities of fuel for steam boilers in rural districts, and he thinks the only method of rendering the use of steam power universal, particularly for agriculture, will be to construct the boiler of the engine so as to utilise the local supplies of combustible material of every kind.

The communication is accompanied by a series of diagrams, from which Plates 3 and 4 have been engraved.

[Mr. Head

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Mr. HEAD directed attention to some specimens of megass, sugar-cane, cotton stalk, wheat and barley straw, reeds, and also a specimen of rhinoceros grass from the Cape—a fuel which, he said, was largely grown there, and burnt most admirably in the engines. He likewise exhibited a full-sized model of the apparatus.

Mr. BRAMWELL observed that allusion had been made in the Paper to the experiments performed at Cairo in March 1874. It was his good fortune to be present at those experiments, and to take part in them. The engine was put up upon the banks of the Nile, and was used to drive a centrifugal pump. Afterwards, a very ingenious and extemporaneous break was applied to the wheel. A strap was put over the fly-wheel of the engine, carrying a weight at one end, and by means of a Salter's balance the strap was fastened to a beam at the other end. The engine tended to raise the weight. If the friction increased it did raise the weight, but immediately it did so the Salter's balance shut up a little; therefore the strain of the balance, which was to be deducted from the weight, became less. If, on the other hand, the friction fell a little, the weight tended to go down, and the Salter's balance drew out to a corresponding extent. In that way the weight was maintained practically steady, and by deducting the average shown by the Salter's balance from the weight on the other side, the net weight upheld by the friction on the fly-wheel was obtained. The apparatus had been made by one of Mr. Head's superintendents in a few hours, and gave excellent results. In addition to ascertaining the consumption per HP., an accurate note was taken of the quantity of water evaporated, which was more to the purpose. He had hoped that this would have been stated in the Paper. The Author, however, had given it in another way, namely, the quantity of fuel consumed per HP. In the sugar factories in Egypt, where megass was burnt in the ordinary manner, very poor results had been obtained. Three or four natives were occupied in feeding one boiler; the door was wide open, and the megass was pushed in by them in enormous heaps, and the air was constantly rushing in. He had the curiosity to go down into the ash-pits under the boilers, where it could be seen that not 20 per cent. of the grate-bars had the hot fuel upon them, the other 80 per cent. letting the cold air stream through, thus detracting from the effect of the fuel in combustion. An enormous amount of manual labour was employed, and the result was very bad. He was not fortunate enough to see the application of the Author's system to the megass boiler. It was not done until after he had left Egypt, but he saw megass burnt in the portable engine on

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the banks of the Nile, and he had every reason to believe that not only would there be a great saving in labour (which was an important item, although labour was cheap there), but a great regularity of firing, and therefore an economical use of fuel. He saw, also, cotton stalks tried, which approached more nearly than did megass to wood fuel. The apparatus dealt with it with the greatest possible success. The subject was one of the highest importance. Many persons might think that there was not very much involved in burning a little straw in a locomotive engine, but when it was remembered that the subject of providing cheap corn was one in which all were interested, and that in those large tracts of country to which reference had been made, if machinery could be introduced for ploughing and threshing, corn would be rendered still cheaper and more abundant, it was evident that the subject was most important to the public generally. When it was seen that the straw or cotton stalks grown on an estate in Egypt could be made by their combustion to develop power sufficient, or more than sufficient, in one case to thresh, and in the other to irrigate, it was evident that the subject was well worth the attention of the leading Institution in England upon engineering matters.

Mr. Frank Garrett concurred in the observations of Mr. Bramwell with regard to the evaporation of water. He was of course unable to assist in regard to the use of Head and Schemioth's engine. He was, however, joint proprietor with his two brothers of a patent dated 21st November, 1871, for the same purpose, being the first such patent on record in this country. It was for a portable engine, so constructed that water might be heated by straw or other light combustible matter, as well as by coal and wood; and interested as he was in the success and publicity of his own system, he could well sympathise with the Author in the delicacy of the task which he had so ably executed. It was the desire not to increase unnecessarily the delicacy of this position, that had decided his firm not to accept the Author on the present occasion as the exponent of their system, which had been invented and communicated to them by Mr. Paul Kotzo, a civil engineer of Pesth. He differed entirely in opinion from the Author in regard to the construction of a boiler for the consumption of straw. He had never seen the necessity of automatic feeding, or of a mechanical rake or pricker for the fire-bars. As far as his experience went they were unnecessary complications, and experienced stokers, who had started many of Kotzo's engines in South America and other countries, had told him that they would

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rather stoke them with straw than with coal or wood. The removal of silica from the tubes and tube-plate was, undoubtedly, a point of importance when burning straw, but the ordinary fire-door giving ready access to these in Kotzo's boilers, the operation was rendered very simple, and he had not found it necessary to attend to this duty more frequently than it was usual to stop for meals when threshing. His tubes were 2½ inches in diameter, as in ordinary portable boilers for coal, and in consideration of the large deposit from the burning straw, and of the ample sufficiency of the heating surface afforded, he preferred them decidedly to 2¼-inch tubes. He believed fully in the use of water in the ash-pit, and that for every sort of furnace, but he had found that an occasional bucket from the feed-water tub answered every purpose, and was better in a portable engine than an unnecessary complication of pipes. It was in respect, however, of the grate area and heating surface that he differed most widely from the Author. In Head and Schemioth's system the grate area per HP. was stated to be 0·93 square foot, whereas in Kotzo's it was 0·52 square foot. The Author allowed 26·1 square feet of heating surface, Kotzo only 19·75 square feet. The proportion between the grate area and the heating surface in Mr. Head's boiler was as 1 to 28, in Kotzo's system as 1 to 37·8. These were startling discrepancies, and seemed to point to grave error on one side or the other. But he believed the discrepancies might be explained, and that the proportions were, in each case, such as had been found most advantageous under the particular system employed. In explanation of the small grate area provided under Kotzo's system, 4·2 square feet for an engine of 8 HP., it might be mentioned that the grate area was augmented or assisted by a preliminary heating chamber, or hopper, in which the straw was thoroughly dried and heated. (Plate 5.) The heating surface of the fire-box was 26 square feet, of the tubes 132 square feet. As the fuel was pushed forward upon the grate proper, ignition took place instantaneously, almost after the manner of an explosion. He believed it was due to the rapid combustion under Kotzo's system that the discrepancies in the grate area and heating surface not only existed, but were inevitable. In these data he had confined himself solely to the question of evaporation. Believing it to be beside the question to enter into details with regard simply to the use of steam, he had avoided all reference to piston area or speed, or even consumption of fuel or water per HP. per hour. He submitted that the subject was one of evaporative efficiency only. The weight of one of Messrs. Garrett's 8-HP. portable straw-burning engines was

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81 cwt., as against 109 cwt. given as the weight of one of the Author's engines. His data were taken with such an engine, which he believed was at present in daily use in the Argentine Republic. The working pressure was 75 lbs. on the square inch, and was maintained in each case with perfect ease and regularity. He mentioned this because there was a prevalent impression that experience and skill were needed to stoke these boilers with straw. He wished to state distinctly that this was not the case, and that any engine-driver of ordinary intelligence could be instructed thoroughly in a few hours. With this engine, on the 28th of May, 1875, he threshed and dressed 30 quarters of wheat, burnt 1,582 lbs. of straw, and evaporated 2,280 lbs. of water; the amount of water evaporated per lb. of straw was 1·7 lb. On the 7th of June, 1875, he threshed and dressed 48 quarters of wheat, burnt 2,196 lbs. of straw, and evaporated 3,504 lbs. of water; the amount of water evaporated per lb. of straw was 1·6 lb. On the 8th of June he threshed and dressed 25½ quarters of wheat, burnt 1,203 lbs. of straw, and evaporated 1,776 lbs. of water; the amount of water evaporated per lb. of straw was 1·4 lb. The total of the three threshings was 4,981 lbs. of straw burnt, 8,160 lbs. of water evaporated; average amount of water evaporated per lb. of straw 1·6 lb. The experiments had been conducted by himself. They were made in the spring under somewhat unfavourable conditions of weather, the straw being taken from stacks and exposed in every way. On one occasion the operations were suspended for some time in consequence of rain, and, as had been stated, the evaporative power of straw depended mainly upon its condition. He was sure, therefore, that at harvest time, under the heat of a summer sun, the result would have been much more favourable. He begged, however, with all courtesy to question the correctness of the formula adopted by the Author, that 3·5 lbs. of unprepared English straw would evaporate 8 lbs. of water under any circumstances—which would be in the proportion of 1 lb. of straw to 2·27 lbs. of water. He did not think that the experiments in this country, to which the Author had referred, would support that formula, even although the straw might have been prepared by careful storage. With the 8-HP. engine, diameter of cylinder 9⅜ inches, length of stroke 12 inches, revolutions 140 per minute, the straw consumed was 20·92 lbs. per effective HP. per hour, and taking each lb. of straw as evaporating 2·27 lbs. of water, it would be found that the engine consumed 47·49 lbs. of water per effective HP. per hour—a result which his knowledge of the excellence of Messrs. Ransome's high-pressure expansive engines would not permit him for one

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moment to accept as correct. The feed-water was heated by one of their ordinary water-heaters, by the exhaust steam. The evaporation was the same as from cold water. He pointed out that the fire-bars for burning straw in Kotzo's boiler (Plate 5) were of bevelled wrought iron 2 inches by $\frac{3}{4}$ inch by $\frac{3}{8}$ inch; they were about 4 inches apart in the centre of the grate, the undue ingress of cold air at each side being checked by a bar $\frac{7}{8}$ inch square about $1\frac{1}{4}$ inch from the boiler plate and 1 inch from the first bevelled fire-bar. This arrangement he considered of great importance. For burning coal, wood, or peat, for which fuels the grate area and heating surface were in excellent proportions, a set of ordinary cast-iron bars were placed upon bearer bars above the straw-grate.

It was pleasant, in conclusion, to reflect that upon one point the Author and he were without doubt agreed, namely, in respect to the benefit which would accrue not only to themselves commercially but to the agricultural community at large, if it could be demonstrated that straw could be profitably used as fuel by the English farmer. He thought the Author had overrated the difficulties in their path, although he feared the time was not yet come for so startling an innovation. He deduced from the articles of Mr. J. B. Lawes "On the Valuation of Unexhausted Manures,"[1] and of Dr. Voelcker "On the Theoretical and Practical Value of Purchased Food, and of its Residue as Manure,"[2] that farmyard or stable manure was not in practice valued at more than 5*s.* to 7*s.* 6*d.* per ton delivered on the farm, and he understood that 1 ton of straw as litter, would not produce more than two such tons of farmyard or stable manure when mixed with excrement. This looked as if the straw might not be worth more than 5*s.* to 7*s.* 6*d.* per ton for manurial purposes; and if this value were accepted, and 24*s.* to 30*s.* were substituted for 20*s.* per ton as the cost of coal delivered to the farm, the aspect of affairs would become more hopeful than appeared from the Author's desponding point of view.

Mr. Longridge said he had not had much experience in the matter, but he had seen in Mauritius a good deal of the use of "bagass," as it was there called. In some of the best sugar estates this and cane straw were the only fuel employed for the Wetzell's mill, the turbines, and for cooking the sugar. The bagass used was generally that of the preceding crop. It was stored in large

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[1] *Vide* Journal of the Royal Agricultural Society of England, 2nd series, vol. xi., p. 4.

[2] *Ibid.*, vol. xii., p. 226.

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stacks, roofed over, and kept till the next year. If taken as it came from the mill, it contained too much moisture. Formerly the bagass had to be supplemented by the use of coal or wood, but he could not state the proportions. There was no difficulty in the feeding. There was a large vault, almost like a baker's oven, into which the men threw the bagass; one man fed the fire with a shovel, throwing the fuel pretty uniformly over. There was a good draught, and capital combustion was obtained. The best mills had tubular boilers, and they not only got up the steam for the engines, but cooked the sugar without other fuel.

Mr. W. ANDERSON had great pleasure in bearing testimony, if any testimony were needed, to the perfection of the system of automatic boiler-stoking described in the Paper. Four years ago he had an opportunity of seeing the 10-HP. engine at Ipswich. The boiler was fed with damp straw, in the way described, on alternate sides of the furnace, and there was not the slightest difficulty in maintaining full speed. He caused the steam to be let down and raised several times; there were few sparks and little smoke. The trial left a strong impression on his mind that the invention was a successful one. In the following year, at the Bedford Show of the Royal Agricultural Society, the stoker was exhibited, and attracted a good deal of attention. The Judges awarded it, deservedly he thought, a silver medal. He regretted that Mr. Head had given so little information with regard to the burning of megass, or the refuse of sugar cane, which perhaps, to Englishmen, was of more consequence than the burning of straw, because many of the sugar-producing colonies depended very much upon the perfection with which megass could be consumed. It was singular that there was so little published information on so important a subject. When making the designs for the Egyptian sugar factories, on which he had presented a Paper to the Institution four years ago,[1] he was completely at a loss with regard to furnaces for burning megass. He was then under the commonly prevailing impression that that kind of fuel required a very large fire-grate. But, as Mr. Bramwell had stated, on looking from below, it was seen that more than half the grate was worse than useless. The Khedive's Chief Engineer of Sugar Factories, Mr. H. J. C. Anderson, M. Inst. C.E., during the season of 1874, modified the grate considerably. He removed the lower half of the fire-bars, raised the others, and placed two D-shaped mouthpieces side by side, 2 feet 6 inches long and 14 inches wide, the bottoms of which were

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxv., p. 37.

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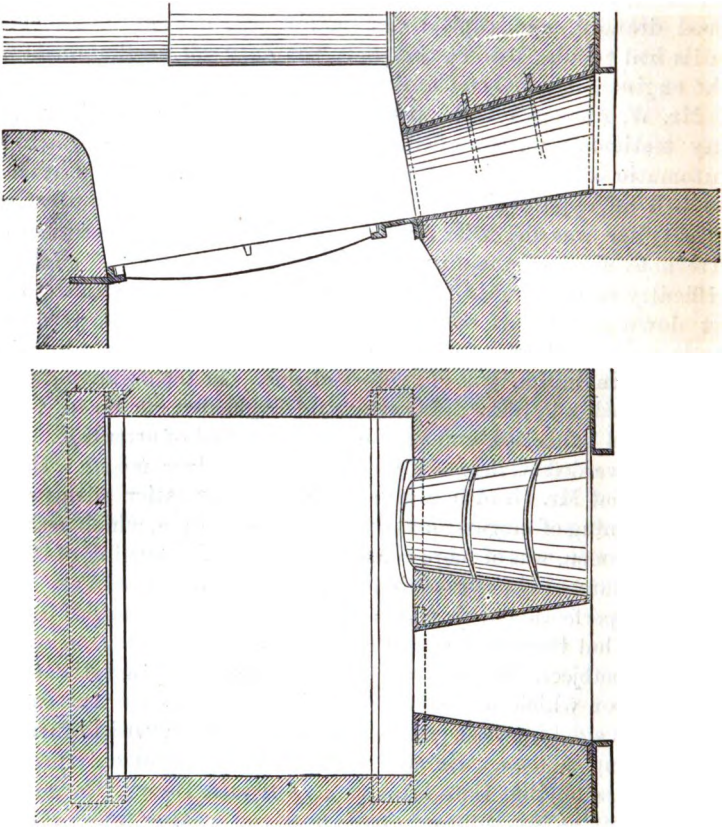
level with the floor of the stoke-hole. The natives squatted on the floor after their manner, with the megass piled around them, and pushed it down the mouthpieces with short sticks. The fuel was put into the fire, as recommended by Mr. Head, not over it. The effect of the alteration had been that, whereas before it had been necessary to use a considerable quantity of coal, during the season of



FURNACE for BURNING MEGASS, as applied to a 60-HP. Boiler.

1875 virtually no coal was used. Coal had only to be burned until a sufficient quantity of megass could be collected; and at the end of the season a quantity of megass, quite equal to the coal consumed, was carried forward to the next season. The apparatus described by Mr. Head was, unfortunately, fitted to one of the factories which, for financial reasons, had not been worked for the last three seasons, and it was impossible therefore to say

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how it was likely to answer. He hoped that during the present season it would be tried at one of the factories now at work. The experiments at Cairo with the 10-HP. engine burning megass did not appear to him to have done justice to the apparatus. The Author stated that the consumption of megass was almost 3 lbs. against 1 lb. of coal; but the experiments of Mr. Bramwell and Dr. Letheby showed a proportion of 2·1 lbs. of megass to 1 lb. of coal. In the Paper already referred to he had mentioned that Mr. Black, the Engineer of the Magaga Factory, in an experiment in which 30,000 lbs. of megass had been consumed, had shown that 1·85 lb. of megass was equal to 1 lb. of coal. The calculations formerly made by him, to demonstrate the possibility of completely finishing the best refined sugar with megass alone, had been justified by the result; and he believed if the Author persevered with his apparatus, 2 lbs. of megass might be rendered equivalent to 1 lb. of coal. It would tend very much to the advancement of this subject if members connected with the sugar industries in the colonies would give information as to the form of furnaces used there.

Dr. SIEMENS said his experience of the form of engine under discussion was confined to what he had seen, as one of the jury, at the Vienna Exhibition a few years ago. Messrs. Ransome, Sims, and Head's apparatus was then worked very satisfactorily, as was also Mr. Garrett's. The jury, he believed, decided that both makers were entitled to an award, not only for their straw-burning engines, but for their exhibits generally. With regard to the relative merits of the two methods, he thought Mr. Head's apparatus deserved the first place, because it contained all the elements of continuous, equal, and systematic feeding; whereas in Mr. Garrett's much depended upon the skill with which the operation was carried on. Mr. Garrett had stated that each time the dried straw was introduced into the furnace an explosion took place. That surely meant that, at the moment when the straw entered the furnace, the combustible matter met an excessive amount of oxygen which had previously accumulated there. No doubt, however, a skilled workman could produce excellent results with Mr. Garrett's apparatus. With reference to the figures brought forward by Mr. Head, which had been contested by Mr. Garrett, he had just made a calculation which might throw some light on the subject. Mr. Head had stated that 1 lb. of coal was equal in heating power to 3½ lbs. of dried straw; and he had given analyses of the coal and of the straw. From this it appeared that the combustible constituents of Newcastle coal were, carbon 80, and hydrogen 5; and of straw, carbon 35, and hydrogen 5;

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making a total of combustible matter in the one case of 85, and in the other of 40: but the hydrogen had a greater calorific power than the carbon, and for comparison might be doubled; so that the figures would be 90 and 45. According to that analysis, straw ought to possess, roughly speaking, half the calorific effect of coal, and it would have that effect if the combustion of both materials were perfect. In the case of straw there was one deduction to be made which did not apply equally to coal; it contained a greater amount of ash in the form of silica; and that ash was the real difficulty to be contended with. There was also a greater amount of water in the straw than in the coal, but that was a matter of less difficulty. In the case of straw 15 per cent. of water had to be evaporated, and in the case of coal only 1·3 per cent. Taking those elements at their utmost value, he considered that Mr. Head's estimate, that 3½ lbs. of straw were equal in calorific effect to 1 lb. of coal, was not excessive; it appeared to him a reasonable amount, provided that something like perfect combustion were obtained. The apparatus, so admirably explained and illustrated, showed that the question had been thoroughly gone into, and the assumption that complete combustion was obtained had been verified. When straw and other similar vegetable matter were consumed, the important point was to remove the ash so as to continue the combustion under favourable circumstances, and this difficulty has apparently been successfully overcome. He thought the thanks of the Institution were due to Mr. Head for the admirable manner in which he had investigated the subject and brought it before the members.

Mr. Cowper desired to confirm the assertion as to the importance of the subject, especially in regard to countries where straw and other refuse, such as gorse, were cheap, and could be used in the machine in question. It was well known that a fair stoker with a good boiler could keep an equable pressure of steam if he had good coal; but with poor, quick-burning fuel, like straw, gorse, ferns, &c., it was an almost impossible task, and under such circumstances, the foreman had constantly to look after the men. He thought the Author had hit upon an arrangement which it would not be easy to improve. He had taken a poor fuel which burnt quickly, and by supplying it regularly and quickly, he virtually made it equal to better fuel which burnt more slowly. With regard to the burning of sawdust and other fine refuse, he had found it required a large grate, a large capacity of fire-box, and narrow fire-bars close together; this arrangement, if ordinary attention were given, answered very well. The stoking was done

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with a bushel basket. The silica sometimes collected to the thickness of 6 inches on the bars, at others of 1 inch. In some large saw-mills he had erected for Messrs. J. Dowson and Company, he had contemplated the use of endless bands to carry shavings and sawdust to the stoke-hole, but on due consideration, he thought it would not be safe, because the combustible matter might burn backwards and produce a destructive result. If sawdust were well burnt, and the engines were economical, no coal whatever need be used. Coal might be made to evaporate rather more water than usual if extreme care were observed in stoking, such as breaking up the coal to about the size of walnuts, keeping a thin fire, having narrow bars and narrow spaces, adding little coal at a time, and by using the damper to the ash-pit with proper precautions, as he had seen carried out whilst acting as judge at the Royal Agricultural shows. One favourable feature of the Author's apparatus was, that it ingeniously forced the fuel in, and thereby produced a mechanical effect upon the fuel burning in the furnace; the fresh fuel was made into a stoking implement, keeping the large quantity of ashes alive, thoroughly stirring them, till they dropped through the bars. No manual labour was required to rake the fire and keep it brisk.

Mr. HEAD observed, in reply, that the object he had in view in designing the engine was to supply the fuel by a mechanical apparatus. In countries where skilled labour was scarce, any machinery requiring it almost invariably failed. Messrs. Garrett's engines had undoubtedly worked satisfactorily, but in many instances skilled men had been employed to work them. In his own experiments he had found it impossible to combine the advantages of a boiler which should generate steam with any kind of fuel which could be grown on the estate, without increasing the heating surface very largely. He had also desired to make an engine which would consume peat, sawdust, and other articles, and which would not require to be altered in order to suit the different kinds of fuel employed. He should be glad to look into the matter with Mr. Garrett from a scientific point of view. With regard to the consumption of megass, he could only echo what Mr. Anderson had said. If those who were connected with the use of steam power in the colonies, where sugar was grown, would furnish rather more freely the information they could give, engineers would be able to construct something which would do a great deal better for them than anything that had been hitherto made. It gave him great pleasure to find that this invention had met with the approval of the members of the Institution.

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Mr. Robt. C. Ransome said he had conducted the trials before the Khedive, to which allusion had been made by Mr. Anderson. He had shown the apparatus with straw and cotton stalks, and His Highness, with his usual acuteness, said, "It is all very well, but I want you to burn megass." He then ordered his servants to fetch some from a small sugar mill close by; but being imperfectly and recently crushed, it contained not only the juice which had not been crushed out by the rolls, but the natural water in the cane. If this megass had been dried a few hours, as was always the practice in the regular use of megass, the result of which Mr. Anderson had spoken would have been produced.

Mr. Stephenson, President, remarked that he had hoped the Paper would have led to a discussion on the enormous waste in the colliery districts, where the small coal was thrown away, wasted in railway embankments, or gathered into pit heaps; whereas it might, at a small cost, be made into a good and cheap fuel for the poorer classes. It appeared to him that there was a practical difficulty in the burning of straw and other light fuel, unless some perfect machine could be invented to admit of the fire-door being kept nearly closed. With all light burning substances the fire-door had to be constantly kept open, so that the air went in, and the fuel was burnt at a great disadvantage. Until something was done by which less air was allowed to get in at the fire-door, by which more perfect combustion could be obtained, he did not think that the experiment would be a success, at any rate in this country.

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EXCAVATING APPARATUS.

During the evening two models were exhibited by Colonel Peile, R.E., Assoc. Inst. C.E., Engineer-in-Chief Indus Valley State Railway, representing a tool for excavating clay in deep foundation cylinders under water, designed by Mr. Gatwell, a sub-engineer of the Indian Public Works Establishment, employed on the construction of the bridge destined to carry the Indus Valley State railway over the Sutlej river. The bridge consisted of sixteen spans of 264 feet from centre to centre; each foundation was formed of three brickwork cylinders sunk to a depth of 100 feet below the dry-weather water-level. The steining of the cylinders was 5 feet thick, and the cylinders rested on heavy framed timber curbs. In one part of the bed, at a depth of 35 feet to 45 feet, a band of compact, intractable clayey silt had been encountered, which resisted long-continued efforts to cut through it. Bull's and Coreacre's dredgers and sand-pumps were tried;[1] chisels and cutters of various forms, applied to the ends of heavy bars jumped up and down, were employed to cut up the surface; divers were kept continually at work, but no progress was obtained in the sinking for many weeks. At last, after repeated trials, Mr. Gatwell succeeded in completing this tool, which rapidly overcame the difficulty. The tool differed from all others which Colonel Peile had seen in cutting from the middle outwards. One form, with two blades, was for cutting in the middle of the cylinder, another, with one blade, was for cutting under the curb. On touching the ground, a hook became disengaged, and the chains being hauled upon drew the blades apart, cutting their way through the soil into a position when they were full and ready to be drawn up. Powerful lifting tackle was required. On one occasion the double tool brought up 30 cubic feet of clay at one lift.

It was not possible by pumping to lay the cylinders dry. The excavation had to be carried on at a depth of from 35 to 50 feet under water. Under such conditions Colonel Peile believed that Mr. Gatwell's excavator would be much more effective in removing hard soil than any other excavating implement yet tried.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxix., p. 213.

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February 6, 1877.

GEORGE ROBERT STEPHENSON, President,
in the Chair.

His Majesty Dom Luis I., King of Portugal, was elected by acclamation an Honorary Member.

The following Candidates were balloted for and duly elected:—Benjamin Hall Blyth, M.A., Robert Reginald Burnett, William Richard Cole, John Carter Park, James Reid, and William Fawcett Wightman, as Members; Adolphus William Ackermann, Thomas Charles John Bain, Henry Osborne Baldry, Stud. Inst. C.E., Charles Edward Botley, William John Boys, Sidney Thomas Bridgford, Capt. R.M.A., Henry Edward Plantagenet Cottrell, John Bruce Crawfurd, Horace Darwin, B.A., Henry Davey, James Gibson Dees, Gavin Gemmell Dick, Hugh Graham Dunlop, George Townsend Fenwick, William Garrett FitzGerald, Edmond Rich Gabbett, Arden Hardwicke, Stud. Inst. C.E., Harry Jones Harman, James Hart, Frederick William Heinke, Henry Francis Joel, Stud. Inst. C.E., William John Jones, George McLellan, William Bayley Marshall, Thomas Mason, Thomas Matthews, Alfred Slater Nice, Carl August Bernhard Nyströmer, Granville Walter Randolph, Stud. Inst. C.E., William Rogers, Percival Walter St. George, Edward Blakeway Smith, Robert Henry Swindlehurst, Recaredo de Uhagon, Irwine John Whitty, Joseph William Wilson, Jun., William Wiseman, Alexander Patrick Wright, and Septimus Young, as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. 7, of the Bye-Laws, had transferred Edward Brotherton Carroll, Henry Gooch, James Lemon, and William Stroudley from the class of Associate to that of Member.

Also that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution:—Francis Abercrombie, George Austen, Cecil Philip William Bond, Harvey Caldicott, Edmund Hynde Bullivant Cracroft, Frank

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GRAHAM FAIRBANK, CECIL FRASER, WYNDHAM HARRY PAYNE GALLWEY, THOMAS HARRY HOUGHTON, EDWARD MAYNE, WILLIAM FRANK PETTIGREW, JOHN PRICE, Jun., PETLEY LLOYD AUGUSTUS PRICE, ROBERT HENRY READ, JONAS MOLESWORTH STAWELL, HENRY WESLEY VOYSEY, ERNEST FREDERICK WELCH, FRANCIS SAMUEL WILDE, and JAMES WILLIAM WYATT.

No. 1,506.—"The Sewage Question."[1] By C. NORMAN BAZALGETTE, Barrister-at-Law.

THE object of this Paper is twofold. First, to limit and define the proper application of the various systems which have from time to time been introduced, as a more or less efficient means of dealing with the sewage of towns. Secondly, to direct attention to certain subordinate questions arising upon the practical operation of these systems.

The Sewage Question has not made much progress, so far as discovery and invention are concerned, during the last quarter of a century, nor does there seem to be much prospect of any new or startling light being thrown upon it in the future. The fact is the field of investigation is nearly exhausted. Earth, air, fire and water have all been resorted to, and the relative merits of processes based upon them are pretty well known, while the resources of chemistry have been ransacked in turn. And yet even now many sanitary authorities stand in an attitude of doubt and expectation, as though, distrustful of the present, they waited for the advent of some miraculous invention which was to supplant all previous doctrine and set the whole question at rest. The causes of such hesitation are doubtless, first, the introduction by empirics of numerous processes which, professing to deal with sewage at a profit, have little or no real value. Secondly, the division among experts themselves, arising from the tendency to study and elaborate special crotchets to the exclusion of a comprehensive form of practice, adapted to the varying conditions and necessities of different localities. Thirdly, the proneness of every

[1] Since the draft of this Paper was placed in the hands of the Secretary of the Institution, a report upon the same subject by Messrs. Read, Rawlinson, and Smith has been made, of which a notice appeared in the "Builder" of December 2nd, 1876. The Author is gratified to observe that the conclusions in that report, so far as they trench upon his views, appear generally to confirm their soundness and accuracy.

The discussion upon this Paper extended over five evenings.

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inventor to overrate the merits and exaggerate the capacity of his own invention. The most recent and conspicuous illustration of this latter defect may be found in the pretensions of Intermittent Downward Filtration, as put forward by the Rivers Pollution Commissioners.

The following classification of the various systems has been adopted for the purposes of this Paper:—

I. Treatment with chemicals.
II. Application of sewage to land, including irrigation and intermittent downward filtration.
III. The dry earth system.
IV. The Liernur or pneumatic system.
V. Seaboard and tidal outfalls.

I. Treatment with Chemicals.

This category may be taken to include all those multifarious processes which, by the admixture of chemicals, have sought the purification of sewage by the precipitation of the dissolved and suspended impurities it contains, and the ultimate realisation of the precipitate in the form of manure. It would be beyond the province of this Paper to attempt even the most meagre summary of the various methods which have been suggested for the accomplishment of these objects. More than a century has elapsed since the first experiments were instituted at Paris, with a view to the extraction of the manurial elements of sewage in a compact form; and since that time, more than sixty permutations and combinations of the original idea of treatment by chemicals have seen the light. But although minute criticism of their comparative merits is impossible, it will still be necessary, for the purpose of defining their appropriate application, that some reference should be made to a few of the more conspicuous modern processes.

Before proceeding to their separate consideration, it may be stated that no chemical process can unaided effectually deal with sewage, but that its application must be ancillary to some other process, as, for instance, the disposal of sewage upon land. This partial incapacity of chemical reagents is attributable to the well-established fact that, in the adoption of any process, one of two results is inevitable; either purification must be purchased at the cost of insolvency, or solvency must be preserved at the sacrifice of purification; in other words, any chemical process to effect puri-

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fication must be worked at a loss. For, conceding even that some of the agents employed can produce a fairly satisfactory effluent, there is no instance upon record where such a result has been obtained concurrently with a commercial profit, or even without a positive loss, although there is abundant evidence to the contrary. This failure must be mainly ascribed to the cost of the chemicals; for while to secure purification it is absolutely necessary that they should not be stinted, the only set off against their cost is the return derivable from the sale of the precipitate as manure. Experience has proved that sewage manures are unmarketable; and even assuming that this were not the fact, still, inasmuch as the value of the manure is pretty nearly in a direct ratio to the chemicals introduced into it, it is clear that, making allowance for waste, there must be an inevitable deficit. Apart, however, from this financial objection, there is a formidable practical difficulty attaching to the use of these processes, which up to the present time has proved an almost fatal bar to their efficient operation, namely, the difficulty of dealing with the enormous quantity of sludge developed by the employment of precipitants. From time to time a number of expedients have been suggested (the most recent by General Scott, R.E., Assoc. Inst. C.E.), to reduce this sludge into a manageable and inoffensive form. But hitherto the success attending the application of these expedients has been so partial, and the difficulty has been so insuperable, that in most cases, where treatment by chemicals has been or is practised, a limited manipulation only has been attempted, and the great bulk of the sewage residuum has been allowed to go to waste. Accordingly, even the doubtful return derivable from the sale of manure, when considered as recoupment for the cost of chemicals, must be subjected first of all to a liberal discount in respect of the difficulty of extracting it in a saleable form. Thus there are three urgent objections to the general adoption of any precipitating process as a means of dealing with sewage. First, it is so costly that purification can only be effected at a serious pecuniary loss; secondly, the extreme difficulty of manipulating the sludge and extracting the manure; and, lastly, the unmarketable character of the extract. A conviction of the truth of these conclusions is steadily forcing itself upon the public mind, and the various companies who are working chemical sewage patents begin to find bankruptcy as one alternative, or abandonment of purification as the other.

As long ago as 1865, Mr. Rawlinson, C.B., M. Inst. C.E., in the Third Report of the Sewage of Towns Commission, epitomised the results gained up to that time, and stated that experience, so far

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as carried; proved that fluid sewage could not be manipulated into a solid manure so as to pay. It remains to be seen whether the results he cited have been substantially varied by subsequent practice.

1. *The Lime Process* may be considered as the progenitor of most chemical methods of treatment in this country, having been adopted more than twenty years ago at Leicester. Its comparative efficiency is proved by the fact that its use survives in some of the more conspicuous instances of modern practice. It was included in the condemnation pronounced by Mr. Rawlinson in 1865; and the opinion then expressed has been confirmed by the Rivers Pollution Commissioners in their first report, 1870. They say (p. 52), referring to the operation of the lime process at Leicester, Tottenham, and Blackburn, "In all these places the plan has been a conspicuous failure, whether as regards the manufacture of valuable manure, or the purification of the offensive liquid;" and again, "the method obviously failed in the purification of the sewage to such an extent as to render it admissible into a river." So far as Leicester is concerned, the accuracy of these statements has been verified by a personal inspection which the Author made of the works in the spring of 1876. The river Soar was then in a state of active pollution, although the most serious effect was observable at a point comparatively remote from the outfall works; but this apparent anomaly was easily accounted for by the fact, that a certain time must elapse before the effluent undergoes complete putrefaction, and it is thus enabled to flow some distance down the stream before arriving at its most offensive condition. About 300 tons of semi-solid sludge were being produced weekly, the estimated value of which was 6*d.* per ton, and yet even at this nominal price it could only command a market among the farmers to the extent of from 400 to 500 tons per annum, or something less than a fortnight's supply, while the remainder had to be got rid of upon 500 acres of drying ground, to the admitted nuisance of the adjacent cottages. The estimated cost for works incurred in respect of this process at Leicester, exclusive of sewerage works, is about £40,000, and the result is a complete failure, both as regards purification and the profitable extraction of a manurial compound. As Leicester is about to abandon the lime process for irrigation, it is unnecessary to dwell further upon the unsatisfactory effect of its adoption there.

At Birmingham the history of the lime process is perhaps more curious, and scarcely less instructive. Previous to 1871, the sewage there was allowed to subside in tanks, before being passed

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into the rivers Rea and Tame. In that year the Town Council, being alive to the defects of the system, and having an additional stimulus to action in a couple of injunctions obtained against them, appointed a committee to report upon the best means of dealing with the sewage of the town. This committee in the course of the same year presented a valuable and exhaustive report, in which (p. 44), after describing the *modus operandi* of the lime process, they pass the following opinion upon its merits:—"The deposit, in the form of a highly putrescible mud, is taken out, dried, and sold for manure; the process of drying being tedious and offensive, and in winter almost impossible. This process is the simplest and least costly of any, but according to the report of the Rivers Pollution Commissioners, the effluent water, though clarified, is not purified or fit to be admitted into a running stream, since it still contains about one-half of the putrescible organic matter, which is precisely what is most important to keep out. Moreover, as the effluent water still contains most of the valuable constituents, the manure is of little value, and it is difficult, and on a large scale might be impossible, to dispose of it."

Bearing in mind that this stricture on the lime process was pronounced as recently as 1871, it is noteworthy that this process has since been selected and applied by Mr. Hawksley, Past-President Inst. C.E., for the purpose of dealing with the sewage of the town. Judging from the information obtained by a personal inspection of the works in the spring of 1876, the Town Council appear to have spared neither pains nor expense to verify the conclusions previously expressed by their Sewage Committee. The population contributing sewage is about 354,000; and, although it is not easy to ascertain the exact expenditure upon land and works at the outfall, yet, approximately, £38,000 must have been paid for 115½ acres of land, then there is the lease of 105 acres, while the cost of the old and new tanks may be calculated at £18,000 and £30,000 respectively, so that the outlay in round numbers has probably exceeded £100,000. On arrival at the works the sewage is treated daily with about 15 tons of lime. It is next passed through eighteen depositing tanks, in which the accumulation of sewage residuum varies in amount and density in proportion to the distance of the tanks from the sewer outfall. The clarified effluent is then allowed to pass by various outlet sluices into the Rea or the Tame, or is disposed of by irrigation on the Corporation land. The amount of sludge produced daily is about 500 tons, an infinitesimal portion of which is converted into

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cement by General Scott's process. At the time of the Author's visit only three men were engaged in the manufacture of this cement. This will afford some criterion of the limited quantity of sludge dealt with. The residue of this enormous bulk of sewage matter, with the exception of a few boat loads, sold to the farmers at £1 a boat load, has to be dug into drying beds covering a large acreage, which is being continually extended. But although the operation of digging it into the ground is incessant, the accumulation of sludge is so enormous as to be almost unmanageable, even the large area at the disposal of the Corporation being insufficient for present requirements—the soil, in many parts to a considerable depth, being saturated and sodden with the impurities which it contains. Such a condition of things, in the neighbourhood of a populous and important town, cannot be too seriously deprecated, both as tending to prejudice the health of the inhabitants and to depreciate the value of property. The machinery by which the process is applied is costly, ingenious, and elaborate, but the result from a sanitary point of view, except as a temporary expedient, can only be regarded as a calamitous failure.

The Corporation of Birmingham have, it is true, been exceptionally unfortunate in their efforts to deal with the sewage difficulty. In 1872, through an extraordinary exercise of land-owning influence, they lost a Bill, the object of which was an irrigation scheme, by a narrow majority upon third reading, after it had previously received the sanction of a Parliamentary Committee. It is to be hoped that the lime process, as practised at Birmingham, is merely a temporary means, pending the adoption of some more substantial and efficient mode, although the permanent and expensive character of the works rather tends to preclude so sanguine an expectation. But it is not only in the creation of this cumbersome mass of sewage mud that the process fails at Birmingham, for the effluent water, to reiterate the expression of the Sewage Committee, "though clarified, is not purified, or fit to be admitted into a running stream." Indeed, at the time of the Author's visit, some of the Corporation land was actually under irrigation by the effluent, and the attendant remarked naively enough, that for this purpose they preferred the effluent to the raw sewage. In that simple remark lay the confession of the practical inefficiency of the whole system; for it proved that the effluent still contained the putrescible organic matter which while the most fertilising is also the most actively polluting property of sewage, and which, therefore, should be

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most jealously excluded from the stream. It may perhaps be argued, that the effect of some of these chemical processes is not only to purify the sewage, but to give to the effluent water a manurial principle non-polluting in itself. This, however, is not the case, at all events with the lime process, for the fertilising power of the effluent is not due to any innocuous manurial principle which is added, but rather to the presence of the nitrogenous organic matter which it has failed to abstract. This view is confirmed by the Rivers Pollution Commissioners in their first report, p. 55, where, in speaking of the lime and Sillar's processes, they say: "The material, however, which it is of the greatest importance to remove from the dissolved constituents of sewage, is nitrogenous organic matter, because it is this kind of organic matter which enters rapidly into putrefaction, and becomes an active agent in the pollution of rivers. This material is represented in the analytical results by organic nitrogen. It is precisely here that both processes signally fail (although the lime process is slightly superior to the other) in accomplishing such an amount of purification as would render the sewage admissible into an open watercourse."

The lime process must therefore be taken to have failed at Birmingham as at Leicester, and if it has failed at Birmingham it will never succeed elsewhere, for all that experience can suggest or skill effect, in providing appropriate mechanical apparatus has been accomplished there. Yet it has failed in the first requirement of any process, namely, to produce a sufficient purification of the treated sewage. Moreover, an enormous amount of comparatively worthless sewage mud is being continually accumulated, the disposal of which is both difficult and offensive.

2. *The A B C, or Sillar's Process* (as worked by the Native Guano Company) claims a Mosaical origin, but it has been more sensational than successful in its public career.

The Rivers Pollution Commissioners, in their first report (p. 57), placed the A B C process, as a purifier of sewage, upon a par with the lime process, but condemned both as failing to purify to such an extent as to render sewage admissible into running waters. In a subsequent Report of 1870, after detailing their investigations, extending over a period of nearly two years, the Commissioners (p. 18) present certain summarised conclusions which may be shortly paraphrased as follows:—1. On no occasion has the purification been sufficiently complete to render the effluent admissible into running water: 2. The effluent is little better than what can be obtained by mere subsidence: 3. The manure

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has a low market value, and cannot repay the cost of production: 4. The manipulations incident to the process are nauseous and offensive.

These conclusions are based upon irrefragable evidence, which is set out in the Report. It may be instructive to extract an answer from the evidence of Dr. Odling, who was examined as an independent witness before the Commissioners, and whose evidence is appended to their Report: *Q.* 51, p. 34 (by Dr. Frankland), "Looking at the whole result of the experiments, do you consider that this is a process to be recommended for the purification of town sewage?—*A.* Certainly not. No doubt this method, like all other methods of precipitation, does keep out a considerable proportion of filth from the river, but there was a great deal of putrescible matter in the effluent liquid, and in comparing this mode of precipitation with others, it did not seem to me that its alleged superiority had any foundation. As regards its superior defecation of sewage, and the high value of the product yielded, I came to the conclusion that it was simply a juggle."

To the sweeping condemnation expressed in this report, one invariable plea has been put forward by the promoters of the process, to the effect that, upon each occasion when the test experiments were made, there was some abnormal cause in operation, which unfortunately disturbed the accuracy of the results obtained, and therefore precluded their adoption as a basis upon which a judgment could be formed as to its general merits and capabilities. But the Commissioners (p. 20, same Report), referring to the failure of the process, completely dispose of this allegation, for they say, "And if this failure be charged upon any alleged unfairness in the conditions under which the experiments took place at Leicester and at Leamington, it must be pointed out in reply, that when the experiment was tried in the laboratory under circumstances which excluded all possible sources of error, the same result was still more unmistakable."

But a still more practical answer was soon afforded. On the 29th of January, 1871, the sanction of the Metropolitan Board of Works was obtained by the Native Guano Company to a proposal that experiments should be instituted at Crossness, in order to illustrate the efficacy of the A B C process. On the 11th of January, 1873, or two years subsequently, Sir Joseph Bazalgette, C.B., M. Inst. C.E., the Engineer, and Mr. Keates, the Chemist, of the Metropolitan Board, respectively presented reports upon the results observed and recorded during that period, the

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gist of which may be shortly stated. The Engineer reported that the cost of producing a manure amounted to £6 6*s.* 4*d.* per ton. The Chemist put the net value of the manure at 20*s.* a ton, but reported "That the effluent water was, on the whole, very good. The A B C treatment so far clarified and defecated the sewage that, looking solely to the physical condition and chemical composition of the water produced at Crossness, I am of opinion that such water was in a fit state to be admitted into any ordinary river without producing a dangerous degree of pollution. I must here again direct attention, however, to the extremely dilute state of the sewage during the experiment. The effect of this was to render the results somewhat inconclusive, as it is, of course, impossible to say, at least from this experiment, how far the A B C treatment would defecate sewage of a stronger character." So that, in fact, such a "very good" effluent was obtained from "extremely dilute" sewage at a dead loss of £5 6*s.* 4*d.* per ton of manure, or at such a price as effectually forbade the general adoption of such mode of treatment. The effect of the Crossness experiments was to afford a forcible illustration of the proposition, that purification can only be purchased at the sacrifice of solvency. It is true Mr. Rawson, the General Manager of the Native Guano Company, asserted in the discussion last year upon the reading of Mr. Shelford's Paper at the Institution,[1] that the Company, having proved the efficacy of the process as a purifier, would, if they had been given time, have also proved its value as a source of manurial profit. But, even assuming that the Company could produce a paying manure, which is more than doubtful, they could never do so concurrently with the production of a purified effluent. The two results of profit, or even solvency, and purification, are inconsistent and incompatible with each other. First, there is a bankrupt expenditure upon chemicals, and the sewage is purified, then money runs short, chemicals are stinted to save their cost, and the sewage returns to its native impurity. Or, it may be for a time, perhaps, that a sort of intermediate course is adopted, which, while aiming at economy of chemicals, at the same time attempts a partial purification; but this can only be a postponement of the inevitable result, for just as surely as the margin of indebtedness becomes reduced, so the margin of impurity is increased.

This proposition receives an apt illustration in the quasi-defence set up by Mr. Shelford, on behalf of the A B C system, in his

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlv., p. 167.

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Paper already referred to. Starting with the statement that the effluent was extremely good, he attributed the financial failure of the process at Crossness to the extravagant use of chemicals there as compared with Leamington, namely, 31·8 lbs. per 1,000 gallons at the former, as compared with 1·86 lb. per 1,000 gallons at the latter place. That is to say, that when, as at Crossness, the admixture of chemicals was ruinously extravagant, the quality of an effluent derived from dilute sewage was very good; but when, as at Leamington, the chemicals were sparingly apportioned, the quality of the effluent was notoriously bad, although even under the latter state of things it does not appear that the Company were enabled to show any commercial profit.

The experience also at Hastings, Southampton, Bolton, and Leeds, all tends to point to the same conclusions. Great things were expected, and have been asserted, of the operation of the process at Leeds; but on account of the impossibility of obtaining a sale of the manure, the contract between the Corporation and the Native Guano Company has been annulled. After two or three years' intermittent experience of the A B C system, the Leeds Corporation have discovered that the process can purify, but has not paid, and it has therefore been abandoned by mutual consent.[1]

Before finally dismissing this process, the value of the manures produced by it remains to be considered. Some years ago Dr. Voelcker, in the Journal of the Royal Agricultural Society, thus stated the results of his analyses of five samples :—

	£.	s.	d.	
No. 1 sample was worth	0	18	6	per ton.
„ 2 „ „	1	13	6	„
„ 3 „ „	0	14	0	„
„ 4 „ „	0	18	6	„
„ 5 „ „	0	14	6	„

Basing the value on a comparison of the manure with phosphate of lime at £10 a ton, and ammonia at £60 a ton, Mr. Keates, the Chemist of the Metropolitan Board of Works, put the value, as has been already observed, at 20*s.*, so that he and Dr. Voelcker are practically agreed in their valuations. These, then, may be taken to be the theoretical values of the manure per ton. But in speculating upon the probability of profit, it is not the theoretical

[1] *Vide* Report of the Society of Arts Conference on the Health and Sewage of Towns, May 9th, 10th, and 11th, 1876, p. 37.

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but the market value which must be considered. This fact was well put by the Chairman of the Council of the Society of Arts in his inaugural address on the 15th of November, 1876, when alluding to the conference held in May last on the health and sewage of towns. He remarked that exaggerated notions had been dispelled by experience, and the public were beginning to learn that, in the disposal of sewage, profit must not be looked for; and that at Leeds, where perhaps more experience had been gained on an extended scale than at any other town, the difficulty had been to dispose of the solid precipitate, arrangements having recently been made with a contractor to purchase it and take it away at 12*s.* a ton, a sum wholly inadequate to defray the cost of treatment.

Enough has been said to illustrate the limits of the capacity of the A B C process, although the results which have been stated could be fortified by much additional evidence.

3. *Sulphate of Alumina and Milk of Lime* (as worked by the General Sewage Manure Company, Limited).—The following particulars of this process as practised at Coventry, obtained at a personal inspection of the works last year, will sufficiently indicate the limits of its ability to purify sewage and produce a profitable manure. The total quantity of sludge precipitated daily is 22 tons, of which 11 tons, or one-half only is dried by Milburn's apparatus, the remaining half being deposited in a semi-solid state upon the adjacent land, or occasionally disposed of in small quantities at 4*s.* a load, or given away to the farmers. The drying grounds were offensive in their character, and the effluent which passed from the tanks into the river Sherburne was insufficiently purified, on account of the sparing admixture of chemicals, the Company being compelled to keep them down in order to avoid the cost contingent on their use. It was stated indeed that the manurial product was in some cases worth as much as £15 a ton, but that, in order to obtain this extreme value, it had to be previously fortified. In other words, the money had first to be put into the sewage, and then taken out again minus the waste.

4. *Phosphate of Alumina* (as practised by the Phosphate Sewage Company, Limited).—This process, the subject of a patent by Messrs. David Forbes and Astley Paston Price, professes to accomplish the defecation and utilisation of sewage, either by precipitation and irrigation, or by means of precipitation only. With regard to its ability to produce a satisfactory effluent, the following analysis of the effluent discharged during certain trials at Tottenham, the results being stated in grains per imperial

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gallon, shows that it does not attain the degree of purity considered necessary by the Rivers Pollution Commissioners:—

Organic matter:—		
In solution	5·74	
In suspension	none	
		5·74
Mineral matter:—		
In solution	57·71	
In suspension	none	
		57·71
Total organic and mineral matter		63·45
Organic nitrogen:—		
In solution	0·47	
In suspension	none	
Total organic nitrogen		0·47
Equal to ammonia	0·57	
Saline ammonia	3·32	
Total nitrogen calculated as ammonia	3·89	

It is difficult to ascertain to what extent this Company professes to deal with sewage apart from irrigation. After having been the subject of experiment at Tottenham in 1871, when the foregoing analysis was obtained, the phosphate process was subsequently, in 1873, applied to the treatment of a small portion of the metropolitan sewage, previously to its being passed upon the Lodge Farm at Barking. When the works were visited by the shareholders and others, after having been in operation for seven months, favourable opinions with regard to the process appeared in most of the leading metropolitan journals, which were afterwards collected and published in a pamphlet form by the Phosphate Sewage Company. The "Times," December 18th, 1873, thus interprets the aims of the Company: "What does this Company profess to accomplish? Certainly not to arrest all or even the chief portion of the valuable fertilising constituents held in solution in town sewage; indeed, according to Dr. Voelcker's analysis, the effluent water after the Company have done with it, is quite as rich in manurial matter as it was before. Hence this process does not claim to arrest and collect in a dry, portable form the wealth of organic matter which our cities are now wasting and the land is crying for; though, like some inventions, it does profess to facilitate the application of the liquid in irrigation

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farming by removing the suspended solid matters which have been found a terrible and, in some cases, an unwholesome nuisance."

This only claims for the process, that it prepares the sewage so as to render the effluent suitable for subsequent distribution upon land; but the preface to the pamphlet goes much further, and asserts its ability to deal independently with sewage, to produce a purified effluent without need of subsequent treatment. An inconsistency of statement seemingly underlies not only the claims put forward by the advocates of these processes, but even the opinions recorded by the chemical experts, namely, that the effluent is equally fit to be passed directly to the stream or to the land.

For instance, Dr. Voelcker, speaking of the clarified sewage of this process, observes, "It is free from any perceptibly disagreeable odour and may be safely run into a watercourse; and having lost none of its mineral fertilising matters, and become slightly richer in saline ammonia, while it has been freed from suspended matters, which greatly interfere with sewage irrigation, the effluent sewage is more valuable, bulk for bulk, for irrigation purposes than the raw liquid."

But if it be true, from the chemical standpoint, that the most fertilising elements of sewage are at the same time the most putrescible in their character—always excepting the ready-formed ammonia retained in the effluent, which is unimportant as regards pollution—how can sewage consistently be described as equally fit for the land or the stream? These propositions appear to be incompatible, and certainly are not reconcilable with the chemical opinions which will shortly be referred to.

However, to recur to the practical history of the process. It was tried in combination with irrigation at the Lodge Farm, Barking, but had to be given up upon the ground of expense.

With regard to its experience at Hertford, where it superseded the lime process, Captain Flower, Engineer to the Lee Conservancy Board, referring to its introduction there, says in a Paper presented to the Conference at the Society of Arts last year (p. 42), "Since then I have received fewer complaints, but the same remark which I made just now as to the necessity of filtering the effluent produced by chemical process applies here. It is true that it may be said filtration is carried on at Hertford, inasmuch as small coke filters are used, but I think the area is too limited. Here again the sewage is much diluted by infiltration of subsoil water."

This testimony can hardly be considered favourable, so far as the

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purifying power of the phosphate process is concerned, and no details of its financial results have come to the knowledge of the Author. Suffice it to say, that when the Corporation of Leeds abandoned the A B C process, the Committee advertised, inviting any one who had a better system to propose to test it at the trial tanks, and that amongst others the Phosphate Sewage Company responded to this request, but the process was not tested, the Company either not foreseeing a successful issue, or being unwilling to bear the cost of a trial.

The Report of Professor Tanner, the Chemist of the Phosphate Sewage Company, seems to dispose of any claims put forward as to its ability to deal independently with sewage apart from filtration or application to land. Referring to its purifying power, he says it can effect "the production of an effluent water which may be applied direct to the land, and is valuable for irrigation purposes; or the effluent, if passed through filter beds of limited area, can be so completely purified, as to be capable of being discharged into any river or stream without causing a nuisance." So while it is stated that the effect of precipitation *per se* is to produce an effluent fit for irrigation, it is also conceded that, if it is to be passed into a stream, a subsequent filtration is necessary for the purpose of preventing a nuisance.

5. *Goodall's Process* (The Clarifying and Utilisation of Sewage Company, Limited) failed at Leeds. It professed to deal with sewage at a cost of 7*s.* 6*d.* per 1,000,000 gallons, but incurred a cost of £4 6*s.* 6*d.* at the experimental tanks, reduced to £2 13*s.* 4*d.* at the larger works.

6. *Bird's Process* (Bird's Sewage Company), applied at Cheltenham and Stroud, was reported unfavourably of by the Rivers Pollution Commissioners with regard to its application at the latter place.

7. *Dugald Campbell's Patent*, 1872.—This process, as well as Whitthread's process, having been brought before the notice of the Institution in the course of last year by Mr. Shelford, M. Inst. C.E., and spoken of in favourable terms as dealing *per se* with sewage, requires to be briefly mentioned. The model works at Battersea were the scene of its practical operation, the agents employed being lime and superphosphate, and the sewage treated at all times of a weak description. First as regards the quality of the effluent. This must have been unsatisfactory, for Mr. Shelford observes that "it was more suitable for irrigation than raw sewage." If so it was plainly unfit to be admitted into running water. The process, even when operating upon sewage at all times weak, failed

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to effect a proper degree of purification. Secondly, as regards the cost of producing so unsatisfactory an effluent, Mr. Shelford's estimate is as follows:—

	£.	s.	d.
Cost of superphosphate and lime per ton of manure	2	13	4
Cost of manufacture	1	8	10
Total cost per ton	4	2	2
Value per ton.	4	7	2
Manurial profit	0	5	0

This shows a profit of 5*s.* a ton; but on some occasions the manure yielded a value of only £3 per ton, when of course this slight profit was converted into a loss. From these figures Mr. Shelford deduced the inference that Dugald Campbell's process may be made to pay its own expenses, leaving the public to bear the expense of labour and drying, or £1 8*s.* per ton of manure produced. In order to appreciate this view, it should be applied upon a working scale. Thus, at Leamington the manurial product was put down at 5 tons a day, which, at £1 8*s.* per ton, represents an expense to the public of £7 a day, or £2,555 a year; or, capitalising at slightly more than 5 per cent., a permanent charge upon a capital of £50,000. And this expense, it must be borne in mind, is for the working of a process which, after treatment of weak sewage, produces an effluent more suitable for irrigation than raw sewage.

8. *Whitthread's Process, patented* 1872, was tested at the Tottenham Sewage Works, the agents being dicalcic and monocalcic phosphate, and a little milk of lime. As regards the quality of the effluent, Mr. Shelford observed that it bore out the favourable opinion expressed by Mr. Hope. But Mr. Hope's opinion, as recorded at a meeting of the Social Science Congress of the same year, scarcely appears to be so unqualified in its praise, for he says (p. 342) "although of course it cannot extract the ammonia in solution, it does remove altogether the other forms of 'organic nitrogen' in solution"; and again, that it "to some extent purifies." It is unnecessary to consider the question of cost, for the Company working the patent failed, and though a report of Colonel Cox has been cited in its favour, it was finally abandoned at Tottenham for Hille's process.

There would be no advantage in multiplying evidence beyond the stage which has now been reached, for the practical experience of any of the many chemical processes—and their name is legion

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—all tends to point the conclusion, namely, the incompetency of any method of chemical treatment to deal independently with sewage. In this respect, what is true of the processes specifically mentioned, is also true of many others which, on account of their number, cannot be referred to; as, for instance, Holden's, Hille's, Lenk's, Suvern's, and Scott's.

The dicta of three eminent authorities will fittingly close this section of the Paper.

Frankland (Rivers Pollution Commissioners, first report, p. 52). "The operations of the chemist have, therefore, been directed chiefly to the soluble constituents of sewage; and have had for their object, either the precipitation in a solid form of the valuable, but offensive, ingredients, so as to convert them into portable manure, or, secondly, the rendering them inoffensive by the action of disinfectants. Although these operations have not been altogether unsuccessful, they have hitherto entirely failed in purifying average sewage to such an extent as to render it admissible into running water. We have formed this opinion both from observations of the polluting effect of such chemically purified sewage upon the streams into which it was admitted, and from the amount of putrescible organic matter revealed by the chemical analysis of the sewage after treatment."

Krepp, on "The Sewage Question," 1867, p. 36. "These instances are enough to prove that solids extracted from fluid sewage cannot be manufactured into dry manure, so as to pay for the trouble. Apart from this, chemical analyses, most carefully conducted, of the results of various processes of deodorisation prove, that none of them have thus far succeeded in precipitating or retaining fertilising parts held in solution, the only substances precipitated being those which are held only in suspense, and which would just as well have been retained by the mere mechanical process of filtering."

Corfield, "The Treatment and Utilisation of Sewage," 2nd edition, p. 222. "All these precipitation processes do, then, to a certain extent, purify the sewage and prevent the pollution of rivers, chiefly by removing the suspended matters from the sewage; but they all leave a very large amount of putrescible matter in the effluent water, and at least all the ammonia contained in the sewage (sometimes they add to it); the greater part of the phosphoric acid is precipitated by some of them, while they increase the hardness of the river water, a matter of great importance if the stream be a small one.

"The manures that they produce are in every case very inferior,

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as may be expected from the known value of the sewage constituents that can be precipitated. They have all failed in producing valuable manure, because the valuable constituent of sewage *par excellence* is the ammonia, which, of course, invariably totally escapes in the effluent water, and is lost to the manure: this shows the futility of all attempts to utilise sewage by precipitation alone."

Surely this concurrence of opinion, coupled with the results derived from practice, justifies the following limitations of the province of chemistry with regard to the Sewage Question.

1. That no chemical treatment can of its own independent ability deal permanently with sewage upon a practical scale, for these reasons—

(*a*) Because it either fails to effect purification, or

(*b*) Because purification is purchased at such a cost as to render the adoption of the process impracticable, or

(*c*) Because it is impossible to manipulate the enormous accumulations of sludge necessarily incident to treatment by chemicals.

2. That chemical treatment has therefore no province as an independent means of treating sewage, and its adoption must be ancillary to the adoption of some other process.

3. That the province of chemistry must be limited to the treatment of sewage in combination with subsequent natural or artificial filtration of the effluent.

4. That a chemical process may be employed with advantage in the case of irrigation or downward filtration, either, when contiguity to human habitation, or limited surface area, requires a more efficient screening of the raw sewage, before it is passed upon the land, than can be effected by mere subsidence or mechanical extraction. In these cases, however, as in every other where chemicals are introduced, the accumulation of sludge is an objection inseparable from their use.

The Author thinks these views must be recognised at last, as he cannot suppose that the state of things disclosed in the most modern American sanitary text-book, published in January of last year, by the State Board of Massachusetts, will continue to hold good in England. Referring to the numberless array of chemical processes from time to time paraded before the notice of the public, it says (p. 333), "This list might be extended almost indefinitely, and seems to be limited only by the bounds of human credulity. In France and Germany the precipitating processes have been given up as inefficient. In England a new 'successful'

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patent process is hawked about every few months, to be soon found only an addition to the list of failures; and the public is perfectly bewildered by the maze of conflicting statements and propositions."

It is to be hoped that the example of France and Germany may be soon followed in this country.

II. The Application of Sewage to Land, including (1) Irrigation, and (2) Intermittent Downward Filtration.

Irrigation.—It will readily be acknowledged that, where land for the purpose can be obtained at a reasonable cost, the practice of broad irrigation presents at once the most efficient and the most satisfactory means of dealing with the sewage of towns. But though the merits and defects of broad irrigation are now generally understood, there are two points which have recently excited the greatest difference of opinion:

(1) Whether a profit can be derived from it; and

(2) What proportion population should bear to acreage.

With regard to the first point, there is abundant evidence, but of a conflicting character.

Thus, from the Parliamentary Return of 1873, it appears that out of twenty-five places practising irrigation, only two professed to show a profit. Swindon exhibited a profit of £12; but Warwick, the large profit of £1,310. With a view of ascertaining what exceptional circumstances were in operation to take Warwick out of the general category, the Author visited Warwick in the course of last year, when the following facts were obtained. The farm was worked up to Michaelmas 1875 by the Town Council, and was then abandoned because it had proved to be a dead loss. It has since been taken by a limited company, composed of members of the Town Council, and no statistics can be had as to its subsequent financial results. The population is 11,000; the area of the sewage farm, 133 acres; the rent paid, £3 10*s.* an acre; the sewage is very weak; the land is clay; rough surface irrigation is practised. Vegetables are grown, but there is no sale for them; and to improve the financial position, a dairy farm was just being started. The effluent goes to the Avon.

The Conference at the Society of Arts last May on the health and sewage of towns was supplied with numerous returns as to the various methods of treating sewage. It had the additional advantage of a Paper by Mr. W. Hope, V.C., as to the profit

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derivable from sewage agriculture, and similar communications referring to the Beddington and Wrexham farms from Dr. Carpenter and Colonel Jones, V.C., Assoc. Inst. C.E. Consequently the judgment pronounced by the Conference upon this point may be taken as based upon a considerable accumulation of the most recent evidence. It is to the following effect (p. i): "It is essential, however, to bear in mind that a profit should not be looked for by the locality establishing the sewage farm and only a moderate one by the farmer." The Author adopts this view; but, before leaving the question of the agricultural value of sewage, he would wish to invite serious consideration to the question of the real value of sewage, as compared with water, for the purposes of irrigation. The use of water as an irrigant is well known, and its effect as a fructifying agent upon crops of a certain kind well established. Can it be shown that sewage produces any appreciable effect, beyond that which might be obtained by irrigation with an equal quantity of water? The kind of vegetable growth produced most successfully upon sewage farms is just that which might be expected to thrive upon water irrigation; succulent roots, grasses, the cabbage tribe, and plants absorbing into their system a large amount of water, are those which flourish best, and the effect upon plants requiring a higher form of nourishment is by many considered doubtful. The measure of nutriment in sewage is the nitrogen it contains, and this exists in the ammonia ready-formed by decomposition which has advanced more or less; and in the organic compounds containing nitrogen may appear as ammonia as the result of subsequent decomposition. These are the pabula of the plant, so far as that particular kind of nourishment is concerned; but is it certain that the nitrogen applied to the land in sewage is actually taken up by the growing plants? Does such nitrogen form indeed the active nourishing principle of the sewage, so far as the vegetation grown upon the sewaged area is concerned? Upon these points it appears that uncertainty exists, even if evidence be not forthcoming to show that the nitrogen does really not produce the effect ascribed to it, and that sewage, therefore, as an irrigant, possesses little or no real value beyond water for agricultural purposes.

In a report upon the results of the use of sewage at the Barking farm, by Mr. Morgan, dated September 1871, there appear two analyses by Dr. Frankland; one of the sewage employed on the farm, and the other of the effluent water draining away from the farm.

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RESULTS of ANALYSES EXPRESSED in PARTS per 100,000.

Description.	Total Solid Matters in Solution.	Organic Carbon.	Organic Nitrogen.	Ammonia.	Nitrogen as Nitrate and Nitrites.	Total combined Nitrogen.	Chlorine.
Barking.							
Sewage from wooden carriers on E., 10.30 A.M. Sept. 5th, 1871 . . .	96·1	2·583	1·752	5·450	..	6·240	22·1
Effluent water from main outfall on F., 1.30 P.M. Sept. 5th, 1871 . . .	91·3	0·676	0·198	0·005	4·143	4·345	13·4

Description.	Hardness.			Remarks.
	Temporary.	Permanent.	Total.	
Barking.				
Sewage from wooden carriers on E., 10.30 A.M. Sept. 5th, 1871 . . .	..	..	..	Suspended matter: Mineral. 5·24 | Organic. 5·60 | Total. 10·84
Effluent water from main outfall on F., 1.30 P.M. Sept. 5th, 1871 . . .	7	39·3	40·0	Few suspended parts.

These analyses present this remarkable fact that, whereas the sewage contains 6·24 of combined nitrogen, the effluent water contains no less than 4·34 of the same ingredient, or more than 70 per cent. of the whole quantity. In considering what amount of the remaining 30 per cent. can be credited to the fructification of the crop, it must be remembered that by far the greater part of this nitrogen was in the form of ammonia—really carbonate of ammonia, a volatile salt—and it can hardly, therefore, be believed that some portion of this was not dispersed into the atmosphere; so that, in reality, much less nitrogen than is shown by these analyses would actually find its way to assimilation with the plant. Whether or not experience bears out this view, it practically raises the questions: Is sewage irrigation anything more than water irrigation; and does sewage, as applied to land, possess any special monetary value? If not, it goes far to explain the financial difficulty which has attached to the working of sewage farms, for it shows that the money paid for the use of sewage as a fertilising agent has been thrown away, and that water, if

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employed in its stead for the cultivation of crops, would have proved nearly, if not quite, as efficacious.

The proportion of population to acreage is a question upon which, although it has formed the subject of much discussion, it is impossible to do more than found a very general conclusion. In fact the proportion is clearly governed by such a variety of circumstances, as character of soil, depth of natural drainage, contiguity to population, strength of sewage, &c., that it would be folly to attempt to set up any definite standard. All that can be done therefore, is to indicate what would be a safe proportion under ordinary conditions, by taking the proportions adopted in various cases, and finding a mean. For example, taking the eleven towns referred to in the Report of the Birmingham Sewage Committee, where the relative proportions of population and acreage are stated, and striking an average between them, a mean result is obtained of 103 persons to an acre. Perhaps, bearing in mind the two things required of broad irrigation, namely, sufficient purification and agricultural return, 100 persons to an acre, the soil being favourable, is a safe proportion for general practice. At the same time if the eleven instances referred to, and which have yielded the above standard, be analytically examined, it will appear how impossible it is to lay down a universal rule. At Bury, with a population of 15,000, the proportion runs as high as 577 persons to an acre, and there is absolutely no effluent; while at Banbury, population 11,500, it is 90 to the acre. At Warwick, population 11,000, 81 to the acre, and at Romford, population 7,000, only 58 to the acre. The explanation of the enormous difference in the proportion adopted in various localities depends no doubt to some extent on the porosity or retentiveness of the soil, but much more upon the depth of soil which remains clear above the level of the subsoil water. For even in broad irrigation it is not merely the surface contact of the sewage with the soil, assisted by the oxidising influence of vegetation, which conduces to the resolution of sewage into its innocuous elements, but above all, its passage through that aerated earth filter which intervenes between the surface and the subsoil water. This is the principle upon which Intermittent Downward Filtration claims to proceed, the capacity of which will now be considered.

2. *Intermittent Downward Filtration* is a new term coined to express a very old meaning, and which claims as a novelty a very old principle. There is nothing in Intermittent Downward Filtration, so far as principle is concerned, which did not exist

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before the so-called invention came forth from the laboratory of the Rivers Pollution Commissioners. Intermittent Downward Filtration is merely the artificial production of what is frequently found in nature, and its only claim to novelty lies in the fact, that though found in some instances, it does not exist in all. There is nothing in Intermittent Downward Filtration which is not sometimes common to irrigation; in fact irrigation sometimes is Intermittent Downward Filtration, in the strongest sense in which the latter system is explained by its advocates. To illustrate this: The theory of those under whose patronage Intermittent Downward Filtration has been introduced as a new system is shortly this, that if deep drainage, say to the depth of 6 feet, be adopted, the proportion of population to acreage may be enormously increased, and, consequently, the surface area correspondingly diminished. But this is the same old principle which accounts for the varying proportions in the practice of irrigation. Take a professed example of Intermittent Downward Filtration, namely, Merthyr Tydvil, and one of irrigation, namely, the Eton Sewage Farm. Where is the difference which constitutes irrigation in one case, and Downward Filtration in the other, save that the conditions at Eton are those of nature and at Merthyr they are imitations of nature? At Merthyr there is artificial drainage to the depth of 6 feet, at Eton there is natural drainage to the depth of 8 feet, so that, as far as deep drainage goes, irrigation has the best of it, and draining therefore to a depth of 6 feet can scarcely be claimed as a startling innovation. At Merthyr Tydvil the filter is divided into plots, and the sewage is applied intermittently to each plot. At Eton the sewage is turned on to one portion of the farm for a while, and then diverted and poured upon another section. The Eton Sewage Farm fulfils all the conditions of Intermittent Downward Filtration, and yet it is called irrigation. But it is not the name that Intermittent Downward Filtration bears which calls for any serious comment; it is rather the careless and erroneous pretensions asserted with regard to its capacity which really demand serious criticism and investigation. Certain standards have been persistently put forward as indicating the capacity of the new system, never justified in the extent to which they go, either by the experiments out of which the new system was evolved, or by the subsequent experience of its practical operation.

To make the bearing of the argument plain, by which it is proposed to establish the fallacious character given to Intermittent Downward Filtration, it will be advisable to state the points to

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which attention is sought to be particularly directed. First, it may be premised that when reference is made to the standards set up by the Rivers Pollution Commissioners, it is not to be inferred from the use of the word "standard" that the Commissioners have actually committed themselves to the publication of any absolute rule. What is intended to be conveyed is that they have stated certain authoritative opinions, as to the proportion population should bear to acreage, first of all with certain reservations, but afterwards in such dogmatic terms that the record of such opinions has become little removed in its character from the promulgation of a definite standard. In the first instance the proportion was variously stated at from 2,000 to 3,300 persons to an acre, with certain reservations as to its effects pending the application of the experiments on a practical scale. It was afterwards claimed that such a test had been afforded by the experience of the system at Merthyr Tydvil, and all reservations were consequently withdrawn. Accordingly, it is proposed to show first, that the proportions stated by the Commissioners in their reports were not justified by the experiments upon which they are based; secondly, to prove that the experience of Merthyr, instead of confirming, entirely refuted the accuracy of the suggested standards; and thirdly, to establish the fact, that in no case does experience warrant the permanent adoption of a larger proportion than 500 or 600 persons to the acre.

It appears from the First Report of the Rivers Pollution Commissioners, that a number of experiments were instituted in their laboratory by Dr. Frankland, extending over the years 1868–1869, for the purpose of determining the effect of the downward filtration of sewage through various soils, of which the following short summary will suffice:—Satisfactory purification of London sewage can be effected through 15 feet of sand and chalk, at the rate of 5·6 gallons of sewage per cubic yard in twenty-four hours; through Beddington soil, at the rate of 7·6 gallons; through Dursley soil, at the rate of 9·9 gallons; through Hambrook soil, barely at the rate of 4·4 gallons; while through Barking soil, purification was not effected at the rate of 3·8 gallons; and Leyland peat might be educated into effecting purification at the rate of 4 gallons.

Before examining these results with a view to found a logical conclusion upon them, it is submitted that whatever the mathematical mean may prove to be, it is still too high, looking to the fact that it is derived from laboratory experiments. A certain margin must be allowed for the well-known unreliability of

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such experiments, as affording an absolute criterion of what will occur in practice. Such an element of unreliability must be a necessary incident of all laboratory experiments, for the experiment is freed from those disturbing influences which attach to a similar operation on a large scale, exposed to the ordinary conditions of nature. The chemist who conducts the experiment adjusts everything with a nicety of methodical arrangement which must conduce to the most favourable results. The earth is carefully packed layer upon layer in the glass cylinder, and that irregularity of composition is avoided which almost invariably occurs in the soil forming the natural filter bed. The chemicals are weighed out in scales, and allowed to mingle with the sewage in accurate proportion, and thus that rough-and-ready admixture which distinguishes the practical application is entirely excluded from the experiment. The sewage itself is probably collected by means of a bucket from the top waters of a sewer, and so those heavier particles are avoided, which, gravitating downwards, pass along the invert, and which distributed upon the land tend to clog the pores of the natural filter. Then again, there is no rainfall to impede filtration, no sunshine to develop noxious exhalations, and no wind to waft such odours in the direction of contiguous habitations. Freed from every disturbing influence, the experiment, proceeding in the uninterrupted quiet of the laboratory, necessarily yields the most favourable results. Laboratory experiments must therefore be discounted before they can be accepted as affording a standard of any real practical value.

But have the experiments referred to been so discounted? On the contrary, they have been strained, and the opinions based upon them exaggerated. To test this: It is clear that for the purpose of arriving at the true indication of the experiments, a process of selection must not be adopted. If a proportion is to be asserted or a standard set up, it must not proceed upon the best or the worst, but upon the mean results afforded by the experiments from which they are derived. But if the six experiments in the Commissioners' Report be grouped together for the purpose of striking an average, the mean result will be too favourable, as two out of the six experiments show negative results. Thus in the case of filtration through Barking soil, not only was no purification effected at the rate of 3·8 gallons per cubic yard in twenty-four hours, but deterioration was actually taking place; so that, for the purpose of obtaining a true mean, a lower figure than 3·8 gallons should be taken to represent the positive result of the experiment. And again, in the case of filtration through Leyland

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peat, the Commissioners merely express a hope that it might be educated into purifying at the rate of 4 gallons per cubic yard in twenty-four hours; so that, for the purposes of a true mean, a lower figure than 4 gallons should be adopted. Nevertheless, both these negative results are for the present purpose treated as though they were positive. Striking an average, the mean obtained indicates that a satisfactory purification of London sewage may be effected at the rate of 5·9 gallons of sewage per cubic yard of soil in twenty-four hours. Now the first suggestion of a standard is to this effect (p. 69 of same Report): "These experiments upon the filtration of sewage through various materials leave no doubt that this liquid can be effectually purified by such processes. . . . . In this way the sewage of a water-closet town of 10,000 inhabitants, could at a very moderate estimate, be cleansed upon 5 acres of land if the latter were well drained to the depth of 6 feet." Setting on one side the discount due to a laboratory experiment, it is clear that, even then, this proportion of population to acreage is not justified in its extent by the mean of the experiments. A population of 10,000 persons to 5 acres is in the proportion of 2,000 persons to 1 acre. The sewage of these 2,000 persons must be taken at 30 gallons a head, the London water supply, for it was upon London sewage that the experiments were made; and as the water supply represents the amount of dilution, and, consequently, determines the strength of dry-weather sewage, it is important that, in applying the experiments, the same ratio of 30 gallons per head should be preserved. To say, therefore, that the sewage of 2,000 persons can be disposed of every twenty-four hours, upon an acre drained 6 feet deep, is equivalent to saying that 60,000 gallons of sewage can be purified every twenty-four hours upon 9,680 cubic yards of soil, or that purification can be effected at the rate of 6·2 gallons per cubic yard in twenty-four hours. But the mean of the experiments was only 5·9 gallons, so that the first standard suggested by the Commissioners is in excess of the mean.

The element of exaggeration becomes more manifest in subsequent utterances. For instance, at p. 128 of their First Report, a population of 3,300 is stated to represent the purifying capacity of an acre drained 6 feet deep, which at once raises the proportion to 10 gallons per cubic yard in twenty-four hours, as compared with 5·9 gallons, the mean of the experiments. In their third Report, p. 51, the Commissioners appear to have cast off the reserve with which they had expressed their conclusions in the first Report, and at the same time to have strained the experiments to their fullest extent. They say: "And whereas 100 acres or

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more might be needed to cleanse, certainly to profitably utilise, the drainage of a town of 10,000 people by means of irrigation, it would need but 3 acres of a porous medium 6 feet deep, worked as an intermittent filter, to oxidise and therefore purify the drainage water of such a town, provided the mass of earth through which it percolated were frequently and effectually aerated, and the foul liquid were so added that every part of this aerated filter had its equal share and equal interval of aeration. The laboratory experiments, on which we build our confidence in filtration thus conducted for cleansing sewage, may be considered conclusive as to the satisfactory and permanent efficacy of the remedy thus provided; and although it is by no means certain that such an apparatus, on the scale needed for a large town, would not itself be a formidable nuisance, yet there is every reason to believe that the water running from it would be sweet and clean."

This extract contains an absolute expression of opinion on the part of the Commissioners, that though the filter might be a nuisance, the sewage of 3,333 persons may be permanently purified upon an acre of land drained 6 feet deep, or that permanent purification can be effected at the rate of 10 gallons per cubic yard in twenty-four hours. But the highest result afforded by the experiments was in the case of the Dursley soil, where purification was effected at the rate of 9·9 gallons per cubic yard in twenty-four hours, while the mean result, as already stated, only justified application at the rate of 5·9 gallons in the same period; and yet the Commissioners have laid down a standard for adoption in practice, which is actually in excess of the highest and most favourable experimental return, and nearly twice as high as the mean result of their experiments. How, then, can it be contended that the experiments have not been strained, and that the conclusions of the Commissioners, even as they stand upon their own experiments, are not fallacious and calculated to mislead?

A different tone distinguished the statements of the Commissioners in their second Report on the A B C process, dated the 4th of July, 1870, in which (p. 19) they say, "It is no doubt very desirable, in the interest of those towns where sewage cannot be dealt with by irrigation, that an experiment in intermittent downward filtration should be conducted on what may be considered a working scale, when all those difficulties would arise which do not show themselves in a laboratory experiment, and when it would be proved whether the process can be conducted on the

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drainage water of, say, 20,000 people, with the efficiency to which our laboratory experiments pointed, and without creating a nuisance."

The contrast between this hesitation of 1870 and the confidence of 1871 is sufficiently striking. In 1870 there are difficulties to be considered which do not show themselves in a laboratory; but in 1871 "the laboratory experiments may be considered conclusive." In 1870 some doubt is expressed as to the possible efficiency of the process; but in 1871 it would require only 3 acres to permanently purify the sewage of a population of 10,000 inhabitants. An experiment upon a working scale was obtained at last at Merthyr Tydvil, under the auspices of Mr. Bailey Denton, M. Inst. C.E., and the Commissioners, in their fourth Report, 1872, were able to point to this practical proof of the accuracy of their theoretical conclusions. They say (p. 55), referring to the works at Merthyr, "They were designed by Mr. Denton expressly for the purpose of realising on a large scale the results of that process of intermittent filtration which had been devised and investigated in the laboratory of this Commission." And again (p. 56), referring to the dilution of the effluent by subsoil water, "Nevertheless, and even assuming a very high degree of purity for the subsoil water, the net result of the action of the soil of the intermittent filters upon the sewage was highly satisfactory, especially when it is considered that the sewage of a town of 50,000 inhabitants was thus purified on about 20 acres of land." And again (p. 102), "That intermittent filtration, conducted either on the extensive or intensive scale, is perfectly trustworthy for the abatement of the nuisance thus created, there is now ample testimony to prove." It thus stands upon record that at Merthyr the sewage of a population of 50,000 has been satisfactorily purified upon 20 acres of land, or in the proportion of 2,500 persons to an acre, and that the apprehension formerly expressed as to possible nuisance has been proved to be without foundation.

Never was there a more complete delusion. Never were exaggerated conclusions, based upon laboratory experiments, more completely confuted than by that very experience at Merthyr, which was quoted and relied upon as confirming their truth. Before proceeding to prove the facts incident to the first practical exposition of Downward Filtration at Merthyr, it is curious to observe how deeply the misapprehension concerning them had sunk into the minds of the Commissioners. In the Session of 1872 Dr. Frankland gave evidence before the House of Commons

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in support of the Birmingham Sewage Bill, and, in speaking of Downward Filtration, had his attention called (*Q.* 3769) to the passage already referred to, in which the Commissioners declared their confidence in its permanent efficacy, but at the same time their apprehension that the apparatus on a large scale might give rise to a nuisance, and he then replied, "Yes, at the time that Report was written we had not seen the Merthyr works. They had only been established a few months." So also Mr. W. Hope, V.C., in answer to the late Mr. Horace Lloyd, in the course of his evidence upon the same Bill, gave this explanation of his not having visited the Merthyr works: "*Q.* 2101. I asked, if there were anything to be learned there, you would go there?—*A.* If I thought I could learn anything more than I am taught by Dr. Frankland's experiments, I should go there." And again, "*Q.* 2103. But you have never gone to see it?—*A.* Because it tallies exactly with Dr. Frankland's experiments. If the result had not been as good as Dr. Frankland predicted, I should have gone." And the same confidence in the Merthyr fallacy, which distinguished the evidence of Dr. Frankland and Mr. Hope, was equally characteristic of that which was given by the majority of the many eminent experts who supported that Bill, so that when the Bill left Committee the fact stood, founded upon a concurrence of the highest testimony in the kingdom, that the experience of the Merthyr filter beds was identical with the conclusions of the Rivers Pollution Commissioners, and that, the reliability of such experiments having been established, they might safely be accepted as a model for future practice. But the most remarkable incident in the whole history of the Merthyr filter beds is that Mr. Bailey Denton, at whose instance they were laid down, appears to have participated to some extent in the general misapprehension, and by his public utterances to have assisted in its dissemination, although it must be at once admitted that they exhibit a large amount of contradictory statement. For example, in a Paper by him in the Journal of the Society of Arts, December 8th, 1871, it is stated (p. 65), "Short as the interval has been since intermittent downward filtration was first suggested by the Rivers Pollution Commissioners, that process has, like irrigation, undergone a change. . . . . The change to which I have referred has arisen on the proof which I have had the satisfaction myself of affording, that vegetation may be grown upon the surface of filtering areas, even when receiving sewage equal to the discharged refuse of 3,000 persons to each acre, thus adding, in the most apposite manner, to the cleansing powers of the soil the scavengering properties of vegetation." And again

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(p. 66), "Having dwelt upon the practice of irrigation, I ought now to explain the process of intermittent filtration as it may be carried into practice, but as I shall presently deal with it when considering 'Land as a purifier of sewage,' I will only state that by adopting the process as technically described, the liquid refuse of from 1,000 to 3,000 persons—and probably more—may be cleansed by the soil of a single acre of land." On what authority does Mr. Denton state that a proportion of 3,000 persons to an acre may be adopted? Is it on the faith of the Rivers Pollution laboratory experiments, or of the experience of Merthyr? Surely not the latter, for (p. 68) he puts the population contributing sewage to the filter beds at Merthyr at 30,000, which, it will be presently shown, is an excessive estimate, and the acreage at 20 acres, which would only justify a proportion of 1,500 persons to an acre, or less by one-half than the proportion previously suggested.

The only way in which this apparent inconsistency can be explained, is by supposing that when speaking of the proportion of 3,000 persons to an acre, Mr. Denton alludes merely to the temporary effect of such a proportion; but that when he has in view the permanent purification of the sewage, the proportion must be reduced to 1,000 persons to an acre. In a Report made by him in 1873, suggesting Intermittent Downward Filtration as the best means of disposing of the sewage of Kew, Mortlake, and Barnes, he says (p. 54), "The quantity of land, actually required for the purification of sewage of average foulness by intermittent filtration, may be calculated at 1 acre for every 1,000 persons if it be drained 2 yards deep, so as to secure 2 cubic yards of filtering material for every square yard of surface. The Rivers Pollution Commissioners deduced from their laboratory experiments that 1 acre of suitable land drained 2 yards deep might suffice for 3,300 people, and in increasing the quantity of land to 1 acre for 1,000 persons, as I propose to do, the object is to avoid any doubt as to permanency of effect."

When Mr. Bailey Denton gave evidence in support of this scheme before Major Tulloch, R.E., Assoc. Inst. C.E., the Local Government Inspector, who held the usual district inquiry preliminary to the grant of a provisional order, he at once admitted that his supervision of the Merthyr works had been limited to five or six occasional visits, and expressed himself unable to speak definitely as to the extent to which the practice of Downward Filtration had been carried there. Under these circumstances, and for the purpose of arriving at an accurate knowledge of the Merthyr facts, it was considered advisable to procure the attendance of Mr. Harpur, Assoc.

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Inst. C.E., the Resident Surveyor, under whose immediate superintendence Downward Filtration had been adopted, and had continued in operation from the time of its introduction in January 1871 until the time of the inquiry in April 1874. His evidence is not a little remarkable, considering that it was actually given as an advocate of Intermittent Downward Filtration, objecting to a proposal which would have this effect, to use his own words, "that the valuable process of Downward Intermittent Filtration would be put off very seriously throughout the country."

The following evidence, extracted from the short-hand notes of the proceedings, shows the actual facts as to Merthyr, and the true conclusions to be drawn from them, as defining the capacity of Downward Filtration to deal with sewage:—

On p. 57 of the Notes Mr. Harpur is asked: "*Q.* Then we may take it that it was only for five months that the sewage of 25,000 people was put upon the 20 acres at Merthyr Tydvil?—*A.* That is the fact; the whole of the sewage. *Q.* And that is the whole of your experience in reference to the power of 20 acres to receive and deal with satisfactorily the whole of the sewage of the 25,000 people?—*A.* Just so. *Q.* Then in taking 50,000 the Rivers Pollution Commission was in error?—*A.* There was not the sewage of 50,000; nothing like it. *Q.* Then the deductions drawn by the Commissioners in their Report, based upon the sewage of 50,000, must therefore be erroneous?—*A.* Yes; they must be erroneous."

Again, p. 69: "*Q.* What do you consider is the population the sewage from which might be safely drained or turned upon the 20 acres at Merthyr Tydvil?—*A.* I have given that a great deal of consideration, and my opinion is that those 20 acres would take the sewage and cleanse the sewage of 12,000 in perpetuity. I do not think they would cleanse the sewage of more than 12,000. *Q.* That is the result of two years' experience and careful watching? —*A.* Yes, it is." So that so far these significant facts are distinctly proved by the Resident Surveyor at Merthyr: (1) That for a short period of five months only the filter beds were exposed to their greatest strain, sewage being applied in the proportion of 1,250 persons to an acre. (2) That the opinion based upon two years' experience is, that if permanent purification is sought, the proportion must not exceed 600 persons to the acre. Before directing attention to the marked contrast between this evidence and the statements of the Commissioners, it will be well to establish its conclusiveness by carrying it a stage further. After stating that he would only recommend Downward Filtration where suffi-

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cient land cannot be obtained for irrigation, Mr. Harpur is asked (p. 60): "*Q.* Under such circumstances as those at Merthyr Tydvil, where the land is exceptionally favourable, you would not put more than the 12,000 to the 20 acres?—*A.* No; I do not think it would be safe generally to place more sewage than that of 500 on an acre. *Q.* Not more than 500 persons to an acre is the result of your experience?—*A.* Yes; it is so."

How far, then, are the experiments of the Rivers Pollution Commissioners substantiated, or their statements justified, by the experience of Merthyr? If Mr. Harpur is accurate in his facts and opinions, their statements are erroneous and their experiments fallacious. Instead of the capacity of the land to receive sewage being continuously tested by the application of the sewage of 2,500 to the acre, the greatest temporary strain to which it was ever exposed was in the proportion of 1,250 persons to the acre. Instead of their opinions that the sewage of from 2,000 to 3,300 persons might be cleansed on a single acre of land, Mr. Harpur states that 600 persons to the acre, in his opinion, represents the capacity of the filters. The issue between these opinions is important, and inasmuch as Downward Filtration is by way of marking a new era in the much-vexed question of the disposal of sewage upon land, it is essential that its capacity should be accurately defined by the experience obtained from its practical operation. The truth can only be ascertained and error refuted by a survey of the evidence which has been supplied by such experience. In order to place the Merthyr facts beyond the range of discussion, it is necessary to examine the evidence relating to them in somewhat tedious detail. Mr. Arnold Taylor, one of the Inspectors of the Local Government Board, having visited the works at Merthyr, presented a Report, dated November 8th, 1872, which may be taken as conclusive up to the time when that Report was made. The following are the most important extracts: "The population of the district draining into the river Taff is estimated at 40,000, of whom about 20,000 are living in houses directly connected with the existing sewers; the other 20,000, having cesspool or surface drainage only, or perhaps no drainage at all, contribute but little to the existing volume of sewage. This should be borne in mind, because I see it constantly stated in the newspapers and elsewhere, that the sewage of the population of Merthyr—*i.e.* 40,000 people—is being successfully purified upon 20 acres of land at Troed-y-rhiew. The fact is, that for some four or five months at most, viz. from January to May 1871, the sewage of 20,000 was run on to the 20 acres of

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filtration area. But after that time, and to the present moment, one-half only of this sewage of 20,000 people has gone to the 20 acres, the other half having, since June 1871, been continuously applied to the 54 acres of adjoining land under ordinary irrigation.

"I do not wish to be misunderstood. The filtration process at Merthyr must be regarded by every one who visits the place as a very great success, and Mr. Denton is justly entitled to the credit of having first applied on a large scale a system which Dr. Frankland had previously worked out in a series of careful laboratory experiments.

"But just because it is so successful, does it seem to me of importance that the exact truth should be stated with respect to earth filtration as a means of sewage purification.

"The exact history of the Merthyr case will be this: That for some five months, say from January to June 1871, 20 acres of land, most exceptionally situated and very carefully prepared, were found sufficient to purify a volume of sewage from 20,000 persons, equal to a daily discharge of say 900,000 gallons, or at the rate of 45,000 gallons per acre per day. That for the next eighteen months, the same 20 acres are found capable of purifying half this quantity, the rest being distributed and purified over the 54 acres of irrigated area.

"When I saw the land at Troed-y-rhiew last August my impression was this: that the 20 acres of filtration area did show signs here and there of saturation, and that though the appearance of the surface and of the crops grown upon it was wonderful, regard being had to the quantity of sewage which had been poured upon so small an area, yet that the appearance of the crops and the surface of the 54 acres of the adjoining irrigated farm was in all respects the better of the two.

"It is stated by Mr. Harpur that he has dug trial holes at various parts of the filtration area, and that in none of them has he found any sign of earth saturation or of offensiveness. Hence it may be argued that by a continuance of the present intermittent system of filtration, one 5-acre area being in use at a time, whilst the other three are at rest, the land is capable of being used for an indefinite period of time.

"This may be so, but what I urge is, that the 20 acres of earth filters at Merthyr purified the sewage of 20,000 people for at most five or six months; that since then they have purified the sewage of 10,000 people, and that by the end of this year or the early part of next they may have ceased altogether to act as continuous earth filters.

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"The Merthyr system may therefore be certainly quoted as an example of successful sewage purification, but the following exceptional favourable conditions and circumstances ought at the same time to be taken into account:—

"First, then, at Troed-y-rhiew, where the filtration areas are situated, there is no population which is likely to be at all sensitive on the subject of nuisance from any offensive smells or emanations.

"Second. The surface soil is light, and of a kind the best suited for active filtration.

"Third. The subsoil, a deep bed of open, porous, water-charged gravel, not only acts most favourably as an open filter, but also gives to the sewage liquid, after it has passed through 6 feet of earth, some three or four times its own bulk of pure water.

"These are favouring circumstances which cannot easily be found in combination. They are found at Troed-y-rhiew, and hence, in my opinion, the main cause of the success of the system of intermittent earth filtration as applied to the purification of the Merthyr sewage. But I believe that this success will be even more marked when the larger area for irrigation purposes is completed, for then, if earth filtration be practised at all, it will only be resorted to on an emergency or in wet or winter weather."

How do the statements of the Rivers Pollution Commissioners stand verified by this evidence? What becomes of the theoretical proportion of 3,300 persons to an acre? or of the illustration afforded by the experience of Merthyr, where, to quote their words, "the sewage of a town of 50,000 inhabitants was then pumped on about 20 acres of land," or in the proportion of 2,500 persons to an acre? Compare this statement with the facts, that, under circumstances so favourable as to be rarely expected in combination, a proportion of 1,000 persons to an acre, according to Mr. Arnold Taylor, was maintained for about five months, but was subsequently reduced to 500 persons to an acre, and so the filters were subjected to a strain somewhat less severe than the ordinary irrigation farm at Bury, where the permanent proportion observed is 577 persons to an acre, and a far less strain than is imposed upon the Eton sewage farm. This proves that irrigation can, upon the principle contended for by the Rivers Pollution Commissioners, namely, cubical capacity of aerated soil, or soil cleared of subsoil water, outdo Intermittent Downward Filtration in its purifying power; in other words, irrigation is, in some cases, naturally more intensive in its operation than a system of Down-

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ward Filtration, for the simple reason that, in some irrigation farms, the subsoil water lies naturally at a lower depth than in a filter bed, where it has been artificially lowered to a depth of 6 feet. With a view of ascertaining the degree of purity of the effluent at Merthyr, various chemical tests were applied. If it be true that deterioration was actually taking place when the proportion of only 500 or 600 persons to the acre was observed, it would seem to be somewhat doubtful whether 1 acre of filter bed drained 6 feet deep could effectually purify even that limited population with permanency of effect; or, to put the case somewhat differently, it would be questionable whether a 6-feet depth of drainage gives a sufficient cubical capacity of oxygen-charged soil to effect permanent purification in the proportion of 500 persons to an acre. This would seem to be the fact, for the results of the experiments at Merthyr in 1871 and 1872, by the Rivers Pollution Commission and the Committee of the British Association, on the utilisation of sewage, clearly indicate that such a gradual deterioration was taking place in the quality of the effluent. The following table, based on the experiments of the Rivers Pollution Commission, exhibits the decrease in the percentage of impurity removed from the sewage by the action of the filters in the interval between the months of June and October 1871:—

	In June 1871.			In October 1871.		
	Quantity contained in Sewage.	Quantity contained in Effluent.	Per-centage removed.	Quantity contained in Sewage.	Quantity contained in Effluent.	Per-centage removed.
Total solid matter . .	54·000	34·600	35·97	49·200	33·480	31·95
Organic carbon . . .	2·788	0·249	91·07	1·282	0·323	74·81
Organic nitrogen . .	0·783	0·056	92·85	0·952	0·107	88·76
Ammonia	4·854	0·075	98·46	1·280	0·058	95·47
Total combined nitrogen	4·780	0·349	92·70	2·058	0·455	77·89

A comparison of the two series of experiments made by the Committee of the British Association gives a similar result:—

In January 1872 the quantity of organic nitrogen removed was 96·43 per cent.
In July 1872 „ „ „ „ 86·55 „

In the above comparisons the effect of the subsoil water in diluting the sewage is not taken into account.

The Committee of the British Association, in their Report of 1872, p. 151, thus summarise the results of their experiments: "The effluent water this summer was not quite so pure as last

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winter, but still four-fifths of its nitrogen was in the form of nitrates and nitrites."

It will have been observed that the most recent evidence referred to, as to the operation of the Merthyr filters, has been that of Mr. Harpur in the spring of 1874. There had then been three years' experience of their action, which might have been considered sufficient to form a judgment as to their effect. And yet, in a Paper, submitted to the Conference at the Society of Arts in 1876, Mr. Denton gives colour and credence to what might have been justly looked upon as the somewhat faded pretensions of Downward Filtration. First of all, he makes the following statement (p. 23):—"We have now had sufficient trial of actual works to assure us, first, that the suggestion which Dr. Frankland based upon his laboratory experiments, to the effect that an acre of suitable soil drained 6 feet deep, and used intermittently, would cleanse the sewage of 3,300 people, can be realised." What is the "trial of actual works" alluded to as proving the practicability of cleansing sewage with such a proportion of population to soil? The specific experience is referred to in the following statement, but it must be observed that the difference between temporary and permanent effect is not always clearly expressed. It is this (p. 24):—"Although experience at Merthyr, Kendal, Walton Convalescent Hospital, and other places, has most conclusively shown that 1 acre of suitable land will efficiently and for a constancy cleanse the liquid refuse of 1,000 people, a fact, the importance of which cannot be over-estimated in those cases where land is very difficult to get and very expensive when obtained, I may be pardoned for stating that I do not wish to be considered the advocate of dealing with the sewage in such a concentrated form under all circumstances." To these allegations the Author makes the following distinct and unqualified reply:—

1. That experience at Merthyr has never proved that the sewage of 3,300 persons could even be cleansed temporarily upon an acre of land, the greatest proportion which ever obtained there being from 1,000 to 1,250 persons to an acre (*vide* the evidence of Mr. Harpur and Mr. Arnold Taylor).

2. That experience at Merthyr has never conclusively shown that 1 acre of suitable land will efficiently and for a constancy cleanse the liquid refuse of 1,000 people; but it has conclusively shown that if permanency of effect be required, the proportion, where the filter beds have a 6-feet depth of drainage, must not exceed 500 persons to the acre.

3. That the case of Walton Convalescent Hospital has never

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conclusively shown that 1 acre of suitable land will efficiently and for a constancy cleanse the liquid refuse of 1,000 people, for the simple reason that the proportion there has never exceeded 400 persons to an acre, as is proved by the following extract from the short-hand notes of the inquiry already referred to, when, in answer to questions, Mr. Denton stated as follows:—"*Q.* Have you ever carried the laboratory experiments of Dr. Frankland into anything like practical effect?—*A.* The Merthyr Tydvil works are nearly three years old, and the works at the Convalescent Hospital at Walton have been in operation four years; once in twenty-four hours the sewage is intermittently applied there. *Q.* What is the population per acre there?—*A.* It varies from 100 to 400. I am not instancing this as a proof that Dr. Frankland's statement is correct." The only further comment to be made upon this evidence of 1874 is this, if the Walton Convalescent Hospital was not cited as substantiating Dr. Frankland's statements, why is it quoted in support of them in the Paper of 1876?

4. That Downward Filtration as practised at Kendal has never conclusively shown that 1 acre of suitable land will efficiently and for a constancy cleanse the liquid refuse of 1,000 people. The facts are given by Mr. Denton, in the Journal of the Society of Arts already referred to, thus (p. 25):—"At Kendal, where there is a population of 13,500, the intermittent downward filtration work has hitherto been confined to about 5 acres of land, contrary to the advice which I gave the Corporation when first consulted, to the effect that 15 acres should be prepared. The experience gained on these 5 acres surpasses all expectation. It confirms, nevertheless, the opinion already stated, that the proper proportion of sewage to land should be that of 1,000 persons to an acre. In this view it appears that the Corporation now concur, for the sewage is not always confined to the 5 acres, but is occasionally applied also to the remaining 10 acres which I had proposed should be prepared for filtration."

Does this mean that the sewage of 13,500 persons has been applied to 5 acres of filter beds, or at the rate of 2,700 persons to an acre? or has no distinction been drawn between population and population directly contributing sewage? To this vague generalisation of statement the origin of the Merthyr misapprehension may be traced. Referring to the return furnished from Kendal to the Society of Arts, it appears that, for this population of 13,500 persons, there are only 500 closets in use, so that it is erroneous to speak of the sewage of a population of 13,500 persons draining upon the 5 or 5½ acres of filtration area. What the sewage-contributing

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population proper is, it is difficult to estimate, but taking the above limited number of closets, coupled with the fact that middens are principally in use, the sewage probably is not derived from more than one-third of the population. Adopting this view, the sewage of a population of 4,500 would have been dealt with upon a surface area of filter bed of 5½ acres (for 5½ acres, and not 5 acres, as appears from a letter from the Borough Surveyor of Kendal to the Author, dated November 13th, 1876, are the accurate dimensions), which yields a proportion of rather more more than 800 persons to the acre. This is, of course, to some extent speculative, in the absence of positive information. But before proceeding to conclusions there are several important elements for consideration. First of all, the sewage is rendered extremely dilute by the enormous infiltration of subsoil water into the sewers; secondly, the depth at which the subsoil water in the filter beds stands below the surface-level is not stated, so that it is impossible to argue upon the capacity of Downward Filtration as practised at Kendal, inasmuch as the whole principle is based upon the cubical capacity which a 2-yards depth of drainage would afford; thirdly, according to Mr. Denton, and also from information supplied by the Borough Surveyor, the whole 15 acres will soon be required for the purposes of filtration, the present limited surface showing a tendency to become clogged. Then, if the Author is right in the assumption that one-third of the sewage proper passes to the filters there, the history of the operation of Downward Filtration at Kendal is this: that for a time the dilute sewage of the town has been applied to the filter beds in the proportion of about 800 persons to an acre; that such filters have shown symptoms of clogging; and it is, therefore, intended to reduce the proportion from 800 persons to an acre to 300 persons to an acre. If this statement of the Kendal experience be an accurate one (and the Author need hardly say that, as he proceeds upon assumption in this case, and is not dealing with facts proven, he is open to correction), there is nothing in any of the cases cited to establish either the soundness of Dr. Frankland's conclusions or the accuracy of Mr. Denton's statements. Merthyr clearly fails at the touchstone of inquiry, Walton fails on Mr. Denton's own evidence, Kendal it is submitted fails on account of the facts stated, and by obvious parity of reasoning from the circumstances at Merthyr.

Surely it is time that the Merthyr fallacy was stamped out, and yet the advocates of Downward Filtration seem unwilling that it should die. The following extracts from a recent correspondence will, however, it is hoped, supply it with a suitable

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apotheosis. Mr. Denton commences his Paper by introducing (p. 25) a letter from himself, dated May 11th, 1875, addressed to Mr. Jones, the Chairman of the Merthyr Local Board, which, will "satisfy the most sceptical that the value of intermittent downward filtration is as great in combination with surface irrigation on a wide area as when adopted by itself on a small one." In this letter, after expressing apprehension lest the extension of the irrigation area should be interpreted as meaning the abandonment of Downward Filtration, he thus concludes: "Will you kindly say if your Board has changed its mind as to the retention of the filtration areas as part of its permanent works, and if so, what has led to such change?" And again, "I am glad to find that Mr. Dyke (the Medical Officer of the district) has the same confidence in the permanency of their action as I have. In his letter to me of the 6th of May last, he says: 'There is still no evidence of any clogging or over-saturation of the beds.'" In his reply (also set out in the same Paper) Mr. Jones states that the Board contemplates no abandonment of the filtration areas, but looks upon them as a "safety valve." Then the Paper concludes, so far as Merthyr is concerned, with the following observations (p. 25): "If anything more than this is needed to prove the thorough success of the intermittent downward filtration work at Merthyr, I cannot do better than point to the following passages of a letter from Mr. Dyke, the medical officer of the district, who wrote me as lately as July last in the following terms." The gist of Mr. Dyke's letter was to the effect that filtration was perfect, the effluent pure, and the vegetables grown on the filters had been eaten without producing diarrhœa; and then the important statement follows "that there has never been any sign of clogging or over-saturation." Can anything more be needed to prove the thorough success of the Intermittent Downward Filtration work at Merthyr? Only this letter from Mr. Harpur, which states how this success has been achieved. It is addressed to the Author, is dated 8th November, 1876, and runs thus:—

"The total area of land acquired by the Board for sewage purposes, including roads, rivers, unsuitable and at present unformed land, is 334 acres.

"The sewage is now being applied to 210 acres, including the 20 acres of filtration areas. Of the land acquired about 90 acres have yet to be formed for the reception of sewage.

"For the last four years no more sewage has been applied to each acre of the filtration areas than to an acre of the irrigated ground.

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"The population draining to the sewage farms is 48,000. Each acre of both the irrigation land and the filtration areas receives the sewage of 229 persons.

"The filtration areas do not show any sign of deterioration.

"It is intended to use them permanently for irrigation."

Can anything more be needed "to prove the thorough success of the Intermittent Downward Filtration work at Merthyr" than the facts—

(1) That for the last four years the filter beds have never received the sewage of more than 229 persons to the acre, and yet up to the present time "there is no evidence of any clogging or over-saturation of the beds."

(2) That the filter beds are to be preserved—for what? to perform *en permanence* the functions of ordinary irrigation.

Conclusions.—1. Intermittent Downward Filtration is merely an artificial production of intensified irrigation, and is a useful process to adopt, where land for irrigation cannot reasonably be acquired, or where the necessary depth of soil free from subsoil water cannot be obtained without recourse to artificial drainage.

2. That there is no evidence to show that a larger proportion than the sewage of 500 persons can be permanently purified upon an acre drained 6 feet deep, though there is positive evidence to show that it must not be exceeded, and that this proportion therefore represents the capacity of downward filtration over and through such area and depth of soil.

3. That Dr. Frankland's experiments are strained in the conclusions drawn from them by the Rivers Pollution Commissioners, and that such conclusions, instead of having been confirmed, have been refuted by subsequent practice.

4. That the statements with regard to Merthyr are without foundation or justification; the true facts being that for five months the sewage was applied in the proportion of 1,000, or at most 1,250, persons to an acre, then of 500 persons to an acre, and afterwards permanently of 229 persons to an acre. That though the formation necessary for downward filtration has been preserved, to all intents and purposes the filters are performing the permanent functions of an ordinary sewage irrigation farm.

III. The Dry Earth System.

The first and most prominent objection to the introduction of this system into any town is, that instead of being substitutive for a water-carriage system, it is merely supplementary to it; for

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there must still be a water-carriage system in every town where the dry earth system is adopted, independent of it, which in its capacity shall be equivalent to such a water-carriage system as would be laid down even if the dry earth system was not practised. Therefore the cost of the dry earth system must be superadded to the cost of the water-carriage system, and thus the expense to be incurred by the town in respect of its drainage must be increased without any additional benefit being conferred, but, on the contrary, enormous additional expenditure, disadvantage, and difficulty.

To make good these propositions, assume that it is proposed to introduce the dry earth system into the metropolis, which may be taken to contain a population of 4,200,000 souls, and a superficial area of 150 square miles, composed to a large extent of roof and paved surface. The rain falling upon this hard surface cannot be absorbed, and must flow somewhere. Can the dry earth system take it? No, for it only proposes to intercept the solid refuse of the town; therefore a system of sewers at once becomes a necessity. Then, again, what is to become of the dry-weather flow of sewage or the sewage proper, the dimensions of which are measured by the water supply of a town? The water supply of London is 30 gallons a head per day, which gives a daily volume of sewage to be disposed of amounting to 126,000,000 gallons in twenty-four hours. Can the dry earth system deal with this great bulk of liquid? It does not profess to. Therefore there must be a system of sewers to receive it, and a system, moreover, of equivalent magnitude to that which would be adopted if the dry earth system were not in the town; for the dry earth system does not reduce to any appreciable extent the volume of sewage produced, inasmuch as its proper province is to intercept the solid matters, with a small portion of the liquid, which would otherwise be carried away in the water supply. Nor does the dry earth system diminish to any great extent the foulness of the sewage, inasmuch as, according to the Rivers Pollution Commissioners, the foulness of the solid refuse is only one-seventh of the foulness of the liquid, and the extraction therefore of so subordinate a polluting element from the sewage could not much affect the degree of its general pollution. Of course some portion of the liquid refuse is disposed of by the dry earth system, and in the sense, therefore, that the volume of foul liquid in the sewers is diminished in quantity and more diluted in quality it may be said that its foulness is reduced.

Again, if the dry earth system is to be a substitutive system, supplanting all other systems, what is to become of the garbage

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and washings of the streets, manure consequent on traffic, liquid refuse from breweries, slaughter-houses, cattle markets, urinals, factories where offensive trades are carried on, and to resolve the dry weather flow into some of its constituent parts, the household slops from kitchens and bedchambers? Either streets must fail to accumulate refuse, such trades and institutions cease to exist, slops and ablutions be banished, or some provision must be made for them. This provision can only be by means of a water-carriage system of sewers. Hence the first proposition becomes manifest, that given the dry earth system, the water-carriage system is still a necessity. If this be so, it follows as a natural consequence that the cost of the dry earth system must be superadded to the cost of the water-carriage system, and that as the dry earth system disposes of nothing which is not disposed of by the water-carriage system, it imposes, therefore, an additional expense without conferring any corresponding advantage.

To illustrate the statement that its operation would be attended with great cost and enormous difficulty the following figures, which proceed upon the assumption of its introduction into the metropolis, may prove instructive.

Moule's Earth Closet System as applied to London.—4½ lbs. of earth per head are equal to 14·66 cwt. per annum, or (on a population of 4,200,000) 3,078,600 tons, cubic yards, or cart loads; or 10,000 cart loads per day for six days in the week. The same quantity would have to be carried out, with the addition of 470 loads of fæcal matter. There are 450,000 houses in London; therefore each cart would deliver earth and remove soil from 45 houses per day. Suppose two pails to each house equal to 900,000 pails, then the figures will stand thus:—

(1) *Prime cost of introduction of system.*

	£.
450,000 houses in London; water-closets removed, earth closets substituted, and metallic wagons provided, say, 700,000 closets, at £10 each	7,000,000
10,000 carts and horses . . . . . { horses . £40 / carts . £20	
£60 × 10,000	600,000
3,078,600 cubic yards of earth taken off land ½ yard deep = 1,272 acres, say two years' supply = 2,544 acres at £300	763,200
Drying sheds (say 600 acres) at £1,200	720,000
	9,083,200
10 per cent. for London depots, offices, &c.	908,320
	9,991,520

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(2) *Annual expenditure.*

	£.
3,078,600 cubic yards carted in 10,000 carts per annum at 12*s.* = £6,000 (1 man 4*s.*, 1 boy 2*s.*, 1 horse 4*s.*, wear and tear of cart 2*s.*)	1,878,000
Labour in digging, loading and unloading carts, railway to London and back at 2*s.* per yard	307,860
	2,185,860

	£.
Representing at 4 per cent.	43,717,200
	9,991,520
	53,708,720

These figures have not been strained; on the contrary, each item has been stated upon the most moderate estimate, and in some cases evidently at too low a figure. So that, after having constructed and paid for a water-carriage system, an additional preliminary expenditure of £9,991,520 would be needed to introduce the dry earth system, and an annual expenditure of £2,185,860 to maintain it, which, capitalised at 4 per cent. and added to the original outlay, represents the enormous sum of £53,708,720, and all this without effecting anything which the water-carriage system is not competent to perform. These figures also illustrate the cumbrous machinery which would be required to give practical existence to the system on a large scale. Where are thousands of acres to be obtained near London for the supply of mould? How is the constant manipulation of sewage refuse to be tolerated in an English town? And, lastly, how are the already overcrowded streets to accommodate the multitude of carts which would be let loose upon them, when the number of such carts would actually exceed the existing number of hansoms and four-wheeled cabs, omnibuses, and tram-cars?

Enough has been said to demonstrate the impracticability of introducing the dry earth system into a populous town. That it has a province cannot be denied, but it is essentially a limited one. It is well adapted for the wants of small rural villages like those of Halton and Aston Clinton in Buckinghamshire, with a joint total of 55 cottages, where it has been adopted, and of detached houses so situated that an abundance of suitable earth can be obtained. So also it may be appropriately applied in the case of detached public buildings under some general control, such as hospitals, workhouses, almshouses, and asylums, always premising, as a condition precedent to its adoption, that the soil in the neighbourhood should be of a porous character, so as to

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be capable of absorbing the liquid house refuse undisposed of by the dry earth system, which is of so decomposing and putrescible a character that if allowed to stagnate in trenches or open ditches it would soon poison the atmosphere and generate malaria. But when it is proposed to introduce it into towns, the conditions are, as has been shown, entirely changed, and the sphere of its usefulness becomes narrowed in proportion as population increases. In fact it may be laid down as a universal proposition, that the applicability of the dry earth system becomes diminished in the inverse ratio to the increase of population to which it is proposed to apply it. The general conclusions, therefore, which must be laid down with regard to this system are—

1. That its adoption in the case of large towns would be costly, cumbrous, useless, and virtually impracticable.

2. That its use must be limited to rural places and detached buildings where a water-carriage system cannot easily be constructed.

IV. The Liernur or Pneumatic System.

This system is one of those which still persists in asserting a pertinacious and pernicious vitality in spite of the experience which ought long ago to have extinguished it, and would have done so, had it not been for the energy of those interested in its survivorship. There appear no less than seven notices of it in the Society of Arts Journal of May 1876, one by Captain Liernur, one by T. A. Van der Kloes, Director of Public Works at Dordrecht, and the other five by Mr. Adam Scott, Captain Liernur's agent in this country. But as the term "Liernur System" may not suggest to the minds of all persons the principle upon which it is based and the machinery by which it is applied, the following description extracted from a pamphlet by Mr. Adam Scott, and verified by the inventor's specification, may assist a proper comprehension of its defects.

"In a building, in any convenient part of the town, is placed a steam engine, which drives an air pump, so as to maintain about three-fourths vacuum in certain cast-iron hermetically-closed reservoirs sunk below the floor.

"From these reservoirs central pipes radiate in all directions, following the main streets. On these central pipes are laid, from distance to distance, street reservoirs sunk below the pavement.

"From the street reservoirs, up and down the street, are main pipes, communicating by short branch pipes with the closets of each house.

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"All the junctions of pipes with reservoirs are furnished with cocks so that they can be shut off or turned on at pleasure, like water mains, and are got at by cock boxes, and turned by keys in the ordinary way.

"The vacuum created in the central building reservoirs can thus be communicated to any given street reservoir, so as to furnish the motive power by which, when the connections with the houses are opened, all the closets are simultaneously emptied.

"When their contents reach the central reservoir, they are in like manner forced through the central tubes to the reservoirs under the central building, and thence transferred by means of vacuum power to hermetically-closed tanks above the floor of the building. From these retorts the matter is decanted in a fluid form in barrels, for immediate transport to the country, by means of hermetically-closed apparatus."

As regards the inception of this system, it is said that Captain Liernur got his idea from the rude pneumatic system in use at Milan, where a vacuum is obtained by first filling the tanks with water and then exhausting them. The water is carted about in ox carts. The system was first introduced into Prague in 1863 for some military barracks; later, into an insane asylum at Hanau. In answer to the statement of the Berlin Commission, that in these places it had proved offensive, and so unsatisfactory as not to be extended, Captain Liernur stated that the first attempts had been improved upon, and that in Holland he had overcome the difficulties which had proved so troublesome at Prague and Hanau. A Commission at the Hague recommended Liernur's system for that city in 1867, but it has never been introduced there. It has had a similar fate lately in Rotterdam. In St. Petersburg, at the beginning of last year, Captain Liernur was making an experimental introduction of his method, with the understanding that the city was not to bear any of the expense, and that no extension was to be made unless the system proved satisfactory. About the same time he was also preparing plans, which he hoped might be accepted, for Gaeta and Naples. His system has been partially introduced at Leyden, Amsterdam, and Dordrecht in Holland, but none of the cities or towns in England have been persuaded to follow the example of their Dutch neighbours.

The objections to the system, which render its adoption impracticable, may be shortly stated. The most important is that which has already been mentioned with regard to the dry earth system, and which, apart from all other considerations, is absolutely fatal,

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namely, (1) that the Liernur system only deals with the solid refuse and a limited quantity of liquid, and is therefore merely supplementary to a water-carriage system, thus entailing additional cost and conferring no corresponding advantage. (2) The machinery by which the pneumatic principle is applied, consisting principally of wrought-iron pipes and chambers, is enormously expensive, and of limited capacity as compared with brickwork sewers. (3) That it is complicated and liable to get out of order. (4) That the closet arrangements for the houses, as well as the operation of decanting sewage, are offensive, and such as could not be tolerated in an English town.

From the evidence afforded by the experience of the system in Holland, it may be premised, in the first place, that in the towns where the system has been introduced in that country, there was absolutely no previous sanitary provision, the whole sewage being either thrown by hand, or allowed to pass away into the tide-locked canals characteristic of the Netherlands towns, so that the introduction of any system was of necessity an improvement on the former unsatisfactory condition of things.

1. *Leyden.*—Plans were accepted for Leyden in 1870. The population is 40,000, and out of this population 1,200 people in the poorest quarter have had the Liernur system applied to their houses. The evidence as to the measure of success with which its operation has been attended has been matter of animated discussion. In a letter, addressed on April 1st, 1873, by the Master of Public Works, J. W. Schaap, to the Magistrate President of the Commission of Manufacturing Industry, he speaks in the following favourable terms of the system (Seventh Annual Report of the State Board of Health of Massachusetts, p. 319): "While it cannot be denied that the expenses of introducing the system and the necessary experiments were greatly in excess of what was anticipated, that the amount received for the fæcal material was less than was anticipated, and that the interest on the money and the instalment paid must be taken into account, yet a favourable judgment, as to the result, must remain." And again, "Therefore the great question concerning this matter is to be looked upon as entirely settled, and the system deserves recommendation to extension everywhere as well as in this city." So far the opinion was satisfactory, but it was soon to undergo a change. In one of his Papers to the Society of Arts, Mr. Scott states, that it was reported that a Government Commission from this country had visited Holland to inquire into the Liernur system. After expressing doubts as to the existence of such a Commission, he refers to their

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reported conclusions (p. 60): "as these have thus, in an irregular way, become public, it is right I should, to prevent persons being misled, record the fact that most of the so-called conclusions are misleading, and some of them, in dealing with matters of fact, are simply untrue, as I can show by official letters in my possession. For instance, one of the statements made is that the system is not to be further extended at Amsterdam and Leyden. I have spoken above as to Leyden." On referring back Mr. Scott appears to have said: "I may add to this that the Commission for Public Works have reported in favour of extending the system to the whole town of 40,000 people. In that report they designate it as 'the system of the future for all large towns.' The Financial Commission have reported in similar terms, as have also the Mayor and Aldermen." Surely there is a strange discrepancy of statement somewhere. In his Paper to the Conference at the Society of Arts on the 9th and 10th of May, 1876, Mr. Scott asserts that the Government Commission, if it existed, has been guilty of untruth, and that the Mayor of Leyden had actually reported in favour of the extension of the Liernur system to the whole city. But how can this statement be reconciled with the following opinion expressed by the Mayor on the 21st of January preceding? Replying to the United States Consul at Rotterdam, he says (his letter being published in the Seventh Annual Report of the State Board of Health of Massachusetts, p. 318), "Meanwhile there exists for the present no intention to extend the system in other parts of the city, because of the considerable expense involved in so doing." And again, in conclusion, "Although the experiment with the Liernur system, taken in this city from a technical point of view, may be said to have entirely succeeded, the financial results, however, must become considerably more favourable before an extension of the system will be resolved upon." If, then, the Mayor, to whom Mr. Scott refers, be taken as the best interpreter of his own sentiments, and of the intentions of his fellow-townsmen, the Government Commission, if it existed, was right after all, and did not state what was "simply untrue"; but Mr. Scott must himself be in error with regard to the "matters of fact." The system, then, is not to be extended at Leyden, on account of its cost.

But perhaps the most suggestive and pertinent evidence which has been contributed, with reference to the operation of the system at Leyden, is that which is contained in a Report by a Committee of the Town Council of Southport, which was appointed, at the time when its adoption for Southport was under consideration, to

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visit Leyden and report upon it. The Report is dated December 15th, 1874. As the statements and opinion expressed apply with equal force to its operation in other localities, and go far to prove the objections which have been raised against its use, it will be expedient to refer to them. The following are the more important passages:—"It should be stated that no slop, or waste water, passes into the Liernur closets. These liquids are disposed of in the quarter sewered on the Liernur system, in the same way as in other parts of the city. Neither does kitchen waste go into the closets, so that the system, as developed at Leyden, is one of collection of human excreta only, and no other duty is subserved by it." "In order to complete the statement of what we observed at Leyden, it is necessary to say that 'sewers,' as we understand the term, do not exist there. The canals which intersect the city in every direction are the sewers, and house drains enter the nearest canal at the most available point, taking apparently the most direct route without the slightest care or regard as to whether they go under houses or not. This primitive method appears to have prevailed from time immemorial." "A pneumatic system of collecting human excreta would, therefore, relieve the sewers of no appreciable amount of their contents under the present, or even a universal watercloset, system. The daily collection at Leyden from the Liernur closet is only at the rate of about a quarter of a gallon per head, so that even if this were much more augmented than would be compatible with any economical manufacture of 'poudrette' the relief afforded to the sewers, however valuable as regards the quality of their contents, could, as regards quantity passed in, be altogether insignificant. It is clear, then, that the pneumatic system will not, if adopted, relieve the borough of the cost of constructing new sewers, which must be of sufficient capacity to carry away, not only the daily flow of between 30 and 40 gallons per head of a rapidly increasing population, but the storm water, which constantly increases in volume as a larger area of the borough is built over and paved, and less of the rainfall sinks into the soil itself." "Captain Liernur himself put down £4 per head of population as the probable cost of applying the system here."

"The impression of your deputation is—

"1. That the system of sewerage already adopted by the Council would be absolutely necessary, even if the pneumatic system were in actual operation in the borough.

"2. That the pneumatic system is highly ingenious and efficient, and probably highly meritorious in a sanitary sense also, though

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no statistics appear to have been collected which would give us a measure of its excellence.

"3. That in a town of so large an area as Southport, relatively to population, the pneumatic sewerage works would be enormously costly to put down and maintain.

"4. That the amount of revenue derivable is very difficult to estimate.

"5. That, from a financial point of view, it would, therefore, be a great experiment; and,

"6. That if experience in England should at any future time demonstrate in a fuller and more complete manner than has been done at Leyden, that the pneumatic system is, as has been claimed for it, 'an engineering, a sanitary, and a financial success,' it will be as open to Southport as to any other place to lay it down and profit by the practical experience of places having larger means to undertake costly experiments."

The above Report proves that the Liernur system is merely supplementary, both in its operation and its cost; that it disposes of nothing that the water-carriage system cannot dispose of without its assistance; and that there is no sanitary advantage to be gained by its adoption. On the question of cost, it is to be observed that Captain Liernur put the cost of introducing the system at £4 per head of population at Southport, as against £2 5*s.* at Leyden. Making allowance for the difference in the price of labour between the two countries, it is probable that £4 per head in England is considerably below the mark; but adopting it for the purpose of argument, and taking the population of London at 4,200,000, the cost of the introduction of this system into the metropolis would reach the enormous total of £16,800,000; and to this expenditure the cost of the main-drainage system, which would be in no sense superseded by the new system, would have to be superadded. It is difficult to estimate what the annual expenditure for the maintenance and working of the system would be; though one thing is sufficiently clear, that no profitable return from the manufacture of 'poudrette' could be looked for in England.

Assuming the cost of maintenance and working at 2*s.* a head, this would represent for London an annual outlay of £420,000, which, capitalised at £4 per cent., would require £10,500,000 to be raised; and adding this sum to the prime cost, it would appear that the introduction of the system into the metropolis would involve an expenditure of £27,300,000. It is worthy of remark that it is customary in continental towns to remove the solid refuse by manual labour, at a cost largely in excess of anything

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in operation in England, and the annual cost, therefore, of the pneumatic system would not commend itself so strongly as an objection abroad as it would in this country.

2. *Amsterdam.*—Mr. Scott, in his Paper of May 1876, on the operation of the system at Amsterdam, quotes passages from a Decree of the Common Council, issued on the 10th of April, 1873—an account of the system by Dr. Egeling, of the Hague, which appeared in "Public Health," November 2nd, 1874—and a letter from Mr. Bergsma, of Amsterdam, dated August, 1874, in proof of the success with which its adoption has been attended there. Without going so far back in point of time, the following extracts from the Seventh Annual Report of the State Board of Health of Massachusetts, United States, published in January 1876, which treats of this system from personal observation, sufficiently indicate the measure of success with which its practical operation has been attended. The writer says (p. 312): "In Amsterdam, the odours from the canals have been for years extremely offensive. They are all open sewers, with no current, and foul gases are constantly bubbling up during the summer. During winter the offence is less, and arises chiefly from the distribution of so much filth upon the ice. Naturally, the authorities were willing to try any system which promised any solution of their difficulty. They adopted the Liernur system in one of the poorest quarters of the city in 1870. On the 10th of April, 1872, Mayor den Tex and the aldermen decided upon its compulsory adoption in seven other small districts. At the present time, it has been introduced for a population of 6,000, or one-fiftieth of the whole city. Mayor den Tex, and the present Master of Public Works, state that it has given entire satisfaction in the poorer parts of the city, where there was absolutely no accommodation before, and where the closets connected with it are out of doors. They state, also, that its first cost renders it doubtful whether it will be extended even there; and that among the better classes the system is considered inferior to waterclosets and cesspools." This extract contrasts strangely with Mr. Scott's Report, as to the extension of the system at Amsterdam. Again: "Captain Liernur's calculations of cost, although very high, provide for the removal of excrement alone. With his system, there must be also sewers for rain-water, street drainage, slops, &c. He would have separate pipes, too, for the drainage of the soil." Again: "By the politeness of Mr. Bergsma, Secretary of the Board of Works of Amsterdam, a friend of the system, I was able to see it in actual operation.

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"The emptying of the tanks was complete, rapid, and, as far as I could see, successful. There was no trace of odour. In the central building, where the matter was transferred to barrels, and in its immediate vicinity, the stench was very great. In the houses of the poorest class, where one house is used by several families, they become soiled, and in some cases filled to overflowing, before any one takes care of them. They become clogged occasionally by coffee-grounds, ashes, &c., which will find their way into them. They are not as offensive as the midden, or privy, still to be found in many large cities. They are in all cases out of doors, and the people who use them prefer them to the arrangements which existed before their introduction.

"In a few houses of the middle class, where they are in the yards, a few rods from the houses, they were scrupulously clean, received frequent washing, and were not offensive. In a primary school-house, where the closets were separated by only a narrow passage-way from the class-rooms, they were frequently washed, and although there was a slight disagreeable odour, there was nothing really offensive at the time of my visit. It is undoubtedly true, as the teacher said, that the closets are much more satisfactory than anything which they had ever had before.

"In the houses of the better class, there is so much complaint of the bad odour from the closets, that they get rid of it as best they can by flushing, with a sudden dash of a large quantity of water, after each use of the seat. Occasionally they become entirely clogged, when the odours are simply insupportable. Mr. Dyck, a resident of Amsterdam, who has also a farm in the country, states that twice in one year this intolerable stench drove him and his family entirely out of his house, until the obstructions could be removed.

"Captain Liernur proposes to meet this difficulty by automatic waterclosets, using only 1 litre of water at each time of use; but they have not been put to the test of practice, and so small a quantity can be of no more service there than in our ordinary hopper closets.

"A part of the original plan was to sell the excrement at a remunerative price; but people of the neater class cannot be prevented from flushing their closets liberally, and the contents of the reservoirs contain so large a proportion of water as to have the general appearance of ordinary sewage, except in colour. Dr. Amersfordt made a contract with the city to take the whole of it, to be delivered on his farm at 11½ cents (U. S. currency) for each 100 litres. The contract expired January 1, 1875, and

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has not been renewed, for two reasons. Dr. Amersfordt states that the distribution of largely-diluted manure from barrels is costly and difficult; also that, when delivered to him in the winter, it is often frozen in the barrels. It is now sold for $16\frac{3}{4}$ cents (U. S. currency), delivered by boats on the farms, during the summer only. In winter it is carted down below the city and thrown into the harbour, as it cannot be sold."

Thus the example of Amsterdam proves the substantial character of some of the objections which have been urged against the system. For instance, it is abundantly clear that the central building, where the process of decanting the liquid into barrels goes on, is an institution which could never be tolerated in an English town; that the closets are of such a character that, though they might be appreciated by the poorer classes in the open air, would be insufferable as applied to the wants of a high-class population; that the manufacture of manure can never be attended with profit, first, because the closets can only be preserved in a sanitary state by a copious use of water, which water is fatal to the efficient manufacture of "poudrette," and, secondly, because it cannot command a sale.

3. *Dordrecht.*—At Dordrecht, the Liernur system was applied in 1875, upon an area of 17,300 mètres, containing a population of 800 inhabitants, distributed over 128 houses fitted with 117 privies. The great feature of its operation there appears to be the manufacture of poudrette on a large scale, and a provisional project for the extension of the system to other parts of the city is contingent upon the success of this manufacture. In his account of the system at Dordrecht, published on the 7th of October, 1875, which appears in the Journal of the Society of Arts of the following May, Mr. T. A. Van der Kloes, Director of Public Works there, states that it would be several months before the "poudrette scheme" would be in regular operation, and he is not therefore in a position to supply statistics with regard to its manufacture. In a letter addressed, on the 20th of January, 1876, by D. W. Hoop, the Mayor of Dordrecht, to the Honourable Frederick Schütz, United States Consul at Rotterdam, the Mayor states that "the extension of the above-mentioned provisional project is delayed, awaiting the results of the poudrette preparations, with regard to which it is thought that sufficient information will be obtained within a few months;" and again, in conclusion, "with regard to the profit on the capital invested in the system, nothing can be stated as yet with certainty, as this community finds itself still too undecided to do so

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definitely. While the experiment is being carried on, we await more definite regulations from the person who has the contract for cleansing the city."

So that so far poudrette has not proved a financial success at Dordrecht. At Leyden, the Mayor's letter proves that it has been a financial failure, and the same result has followed the manufacture of manure by Dr. Amersfordt at Amsterdam. In addition to this practical experience, the Report of the State Board of Health for Massachusetts (p. 317) concludes by saying, "It should be remembered that a similar experiment failed in Amsterdam twenty years ago; that the Paris poudrette sold for one-twentieth of the value placed upon it by the chemists; and that an English company has become bankrupt in attempting to pay 2 francs a cubic mètre for the contents of the cesspools in Paris, leaving several hundred thousand cubic mètres at Bondy, of which the authorities would be glad to rid themselves."

Surely nothing more is wanted in the way of practical proof to point the irresistible conclusion: that though the Liernur system may be used with partial and costly advantage in the tide-locked cities of the Hague, where a system of sewerage is said to be impracticable, the population is not fastidious in its notions, and anything in the nature of a system must be an improvement on the previous unsanitary condition, it can never for one moment have a place in the operations of the English engineer.

V. Seaboard and Tidal Outfalls.

Having regard to the unsuitability and costliness of chemical processes, and of the dry earth and Liernur systems, and the many difficulties, financial and otherwise, which attach to the disposition of sewage upon land, there can be but little doubt that, given a seaboard town, the proper destination of the sewage is the sea. By some, who insist strongly on the value of sewage, it has been objected that such means of disposal are, in fact, an absolute waste of most precious material—material which, if properly handled, must constitute in itself an almost inexhaustible mine of wealth. But day by day the belief that sewage possesses any recuperative value is becoming rudely dispelled, and the doctrine is gaining ground that, instead of keeping sewage at the door as though it were a friend, the right view is to treat it as an enemy, to get rid of which by any means or at any cost should be the primary consideration.

But though such an outfall certainly suggests, in the case of a

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seaboard town, a natural, economical, and feasible method of dealing with its refuse, there are a few points affecting its construction and position, such as the propriety of tide-locked outfalls, the course of currents, and silting-up, which are more or less matters of controversy. Into the first of these points, a tide-locked outfall, it is not proposed to enter in this Paper, as it comes more properly within the province of a discussion upon the principles of sewer construction than the disposition of sewage at the outfall. As to the second point, namely, course of currents, it may be laid down as a general rule that, assuming any doubt to exist with regard to the force or set of the currents to which the sewage is to be committed, careful float observations should be taken with a view to preclude the possibility of its being returned upon the beach. If such precautions are taken, there ought to be no special difficulty in guarding against the occurrence of such a return. The last point, or the question of silting-up at the outfall, is one which affects tidal rivers rather than marine outfalls. But if the site for such outfall be judiciously selected, and proper means be taken, in the town which drains to the outfall, for the exclusion of silt and heavy matters by catchpits and an efficient system of scavenging, there can be little reasonable apprehension of silting-up taking place. At the metropolitan outfalls, no less a quantity than 120,000,000 gallons of sewage, taking the dry-weather flow alone, is passed daily into the river—a volume of sewage equivalent to a fair-sized stream—and yet no silting-up has occurred. In fact, it would seem to be a logical inference, in the absence of disturbing causes, that where the velocity of the current into which the sewage is discharged is greater than the velocity of the current which carries it down through the sewers to the outfall, there cannot be much danger of silting-up or interference with the navigable channel. Of course it is difficult to frame a rule to meet all cases. Much must depend upon the means taken to exclude heavy matters from the sewers, and much upon the character of the locality sewered, some localities producing far more detritus than others. Then, again, the amount of sewage discharged, the sectional area of the river, the volume of water in its channel, and the velocity of the current, are all items in the consideration of the propriety of the outfall, so far as silting-up is concerned. But still it may be accepted as a generally sound proposition, that where efficient means are adopted for the exclusion of heavy matters, such as road detritus, from the sewers, sewage may be discharged into tidal rivers without any material amount of silting-up taking place at the outfall.

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This completes the classification which the Author adopted for the purpose of reviewing the various processes or systems in practical use for the disposal or utilisation of town sewage. He now ventures, referring once more to such classification, to submit the following definite conclusions for the consideration of The Institution of Civil Engineers, in the hope that they will induce such a discussion as may tend to promote a more unanimous opinion, than at present appears to exist, upon the various questions which attach to their consideration :—

1. Treatment with Chemicals.

   Conclusions :—No chemical process can efficiently deal single-handed with sewage, but must be assisted by subsequent natural or artificial filtration of the treated sewage, and therefore no chemical process *per se* should be adopted for the purification of town sewage.

2. Application of Sewage to Land.

   (*a*) *Irrigation.*

   Conclusions :—That where land can be reasonably acquired, irrigation is the best and most satisfactory known system for the disposal of sewage. That no profit must be expected from the cultivation of crops by the sanitary authority, and only a moderate one by the farmer. That no definite standard can be laid down as to the proportion population should bear to acreage.

   (*b*) *Intermittent Downward Filtration.*

   Conclusions :—That Intermittent Downward Filtration may be practised, where irrigation cannot be reasonably adopted. That experience shows that the permanent proportion of population to acreage, where land is drained 6 feet deep, should in no case exceed 500 or 600 persons to an acre. That the term Intermittent Downward Filtration means no more than the production by deep drainage of a state of things frequently found in irrigation, and that irrigation can in some cases accommodate a larger proportion of population to acreage than Intermittent Downward Filtration. That Intermittent Downward Filtration, as expounded and explained by the Rivers Pollution Commissioners, has never had and never can have any practical existence.

3. The Dry Earth System.

   Conclusion :—That the dry earth system can never be adopted for the purpose of dealing with town sewage,

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but may be occasionally used with advantage in small hamlets or detached buildings and institutions.

4. The Liernur or Pneumatic System.

Conclusion:—That the Liernur system is of such a character that it should never be imported into an English town.

5. Seaboard or Tidal Outfalls.

Conclusion:—That towns situated upon the sea-coast, or within the tidal range of rivers, should avail themselves of the means of outfall thus presented, as affording the most economical and efficient means of dealing with their sewage, careful regard being always had to the position of the outfall. That proper precautions being observed for the purpose of excluding silt from the sewers, and care being taken in the selection of outfalls upon the banks of tidal rivers, there is no reasonable danger of the silting-up of the navigable channel.

[Discussion.

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DISCUSSION.[1]

Mr. BAZALGETTE said he had started a somewhat novel view, namely, the comparative values of sewage and of water as irrigants. He wished it to be distinctly understood that that view was only suggestive. It was not put forward as a well-matured and digested theory, or in a dogmatic spirit, but to elicit remarks from those who were more competent to form an opinion upon its merits than he was. In the Paper it rested upon a single analysis by Dr. Frankland, which went far to confirm its accuracy. At the same time he was not in a position to say whether the general results of practice would support it.

General SCOTT was unwilling it should go forth, after all the proofs to the contrary, that no method of precipitation had been found sufficient to purify sewage water. The Author had stated that there would be no advantage in multiplying evidence beyond the stage which had now been reached, as practical experience showed the incompetency of any method of chemical treatment to deal independently with sewage; and amongst the conclusions drawn in the Paper was that where land could be reasonably acquired, irrigation was the best and most satisfactory known system for the disposal of sewage. Five years ago, when General Scott first introduced his system at the Society of Arts, he took occasion to guard against the supposition that sewage water could be purified by precipitation, and the propositions he laid down, for the final purification of contaminated water, were that no artificial process, whether chemical or mechanical, could compare with filtration through a considerable depth of soil and over a wide area relatively to the water to be dealt with. The Author stated "that the province of chemistry must be limited to the treatment of sewage in combination with subsequent natural or artificial filtration of the effluent" (*ante*, p. 121). He had said, on the occasion referred to, "My scheme makes no claim to the complete purification of sewage water, or to supersede irrigation or filtration, when these processes can be carried out, nor does it pretend to extract from the water those highly fertilising but soluble substances which are known to exist in sewage."[2] It was clear, then, that these opinions as to the inefficacy of chemical treatment to purify sewage water were in accord, and he objected to being classed with those who thought otherwise. It was admitted, "That a

[1] The order of the speakers has been slightly varied in the endeavour to approximate to the classification adopted by the Author.—SEC. INST. C.E.

[2] *Vide* "Journal of the Society of Arts," May 17, 1872.

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chemical process may be employed with advantage in the case of irrigation or downward filtration, either, when contiguity to human habitation, or limited surface area, requires a more efficient screening of the raw sewage, before it is passed upon the land, than can be effected by mere subsidence or mechanical extraction" (*ante*, p. 121). General Scott advanced no more, but from this point he differed with Mr. Bazalgette. Mr. W. Hope, V.C., had said, "It is because, in my judgment, sewage irrigation cannot be carried out from the utilisation point of view without storage tanks, that it becomes necessary to deal in some way with the sludge, because if you store you cannot avoid deposition." The Author, however, apparently attributed this necessity to the use of a chemical process, for he added, "In these cases, however, as in every other where chemicals are introduced, the accumulation of sludge is an objection inseparable from their use." Or, in other words, that the chemicals were somehow responsible for any difficulty in getting rid of the sludge and for its accumulation. General Scott did not mean to say that the use of chemicals did not increase the bulk of the sediment, but he denied that they made it more difficult to deal with. In the Birmingham Sewage Enquiry, to which reference had been made, Mr. Hope stated (p. 175), "There is really so little smell about a sewage farm except from the solid matter. I have on my own to take out the sediment. I have no use to put it to, and it accumulates." The sludge then accumulated without the use of chemicals. He should like to draw a comparison between the untreated sludge which had sometimes to be got rid of, and the sludge treated with chemicals. At the same enquiry Mr. Hawksley spoke of untreated sludge as "a very abominable thing" (p. 248). Dr. Letheby said (p. 436) it caused such a nuisance that he "could hardly endure the smell," and Mr. Hope said (p. 162), "It stinks worse than anything I ever smelt out of Constantinople." But what was the condition of the sludge when lime was used? Dr. Frankland remarked (p. 263), "I should prefer to treat it with lime alone, and to use the sludge according to General Scott's process, which does not occasion the slightest nuisance." The question was also asked (p. 276), "Or at Dunton; would there be any nuisance caused by the depositing process and by the use of chemicals?" (It was an error to suppose that the Birmingham scheme was a scheme of irrigation pure and simple; it was a mixed scheme, and it was intended to precipitate the sludge at Dunton in tanks.) The reply was, "There I should apprehend no nuisance whatever if lime were employed." Again, Dr. Frankland testified (p. 278) that he had sludge produced by

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precipitation with lime thrown on the ground before him, and that it "was absolutely inodorous." Dr. Voelcker and Dr. Odling gave testimony to the same effect. Nor was it only on the strength of what these gentlemen had stated that reliance could be placed upon the good effect of lime in reducing nuisance. Mr. Rawlinson had been quoted amongst others as one who had condemned the lime process, and the system was spoken of as one which the various River Pollution Commissioners had deprecated. So far, however, from that being the case, one of the earlier Commissions[1] stated, and Mr. Rawlinson signed the report, "Without going so far as to say that the precipitation by lime is a perfect process, or that it can in all cases be adopted, we feel satisfied that it does, to a great extent, fulfil the purpose for which it is employed, so far, at least, as the purification of rivers is concerned." Then, after adverting in strong terms to the silting up of rivers by throwing sewage into them, the Commissioners added, "The lime process does effectually remove the solid suspended matter, and in so far accomplishes a great and manifest good." In reference to the results obtained by the process he had attempted to apply to the sludge, the case of Birmingham had been quoted, and it had been stated that an infinitesimal quantity of sludge had been converted into cement. He was willing to admit that the quantity was small; the most ever made in one week was 5 tons, and sometimes the amount was only 3 tons. No surprise would therefore be felt that on that scale a cement manufacturing process was not particularly remunerative. The Chairman of the Sewage Committee, however, after the process had been under operation for some time, stated, "The results of our experiments lead me to believe that (the value of) it (the cement) cannot be less than £2 per ton. Even with our imperfect appliances, we have produced a good cement." Since that time a great change had taken place in the amount of sewage admitted into the tanks. There was a peculiarity in the sewage of Birmingham not met with elsewhere. Owing to the nature of the manufactories of the town a large quantity of salts of iron, chloride of iron, and sulphate of iron, passed into the sewers, and the result was that the lime added was to a large extent carried away in solution. It frequently happened that no lime whatever for half an hour or an hour was precipitated with the rest of the solid matters. He need not say it was a difficult thing to make cement when there was no lime present. It was then necessary to add the lime, and

[1] *Vide* "Sewage of Towns Commission," 1857, pp. 23 and 24.

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that increased the expense of the process, and detracted from the quality of the cement. Still he thought it must be admitted as probable, by all who had gone into the Birmingham case, that the sludge which had to be dealt with might perhaps be treated more satisfactorily by the cement process than in the way now chiefly followed. Mr. Bazalgette had stated that the operation of digging it into the ground was incessant, and that the accumulation of sludge was so enormous as to be almost unmanageable; he also admitted that frequently it might be necessary, or at all events advisable, to employ some method of precipitation. If so, what did he propose to do with the sludge? General Scott's suggestion was this:—lime was the cheapest precipitant; the best way to get rid of the deposit produced was to burn it; the deposit when burned would make good agricultural lime, or lime for building purposes, or, by adding clay, if there were not any with the sewage, it would make good cement, and therefore the wise thing to do would be to make it into cement, since it would not sell as manure. He was a great admirer, as every one must be, of the Main Drainage of London; but he was not at all certain that, at some future time, the question might not be asked, why the sewage sludge had been allowed to silt up the river, instead of being made into cement?

Mr. W. Crookes begged to be regarded simply as an independent man of science, who for some years had made this subject his special study, who had watched the different processes in actual operation, and who had experimented alike in glasses containing a pint of sewage and in tanks holding millions of gallons.

The Sewage Question required to be considered from various points of view, and demanded for its successful solution the intelligent co-operation of several professions. The engineer had to devise the most efficient means of bringing the polluted waters, before they had time to putrefy, to some convenient spot below the town, in the selection of which there was no little difficulty. He had to arrange all the mechanical details of the process selected, and unless these were judiciously contrived and adapted to the exact circumstances of the case, the most powerful chemical agencies would be employed at a disadvantage, or altogether in vain. Not less important was the sphere of the chemist. He had to decide upon the efficiency of the means employed for the purification of polluted waters, and to ascertain in how far they might be considered successful. The medical practitioner, especially the public officer of health, and the practical agriculturist, were also entitled to he heard. Nor must it be forgotten that the

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subject had also a financial aspect, which professional men were too apt to overlook, but which was tangibly brought home to the minds of the ratepayers, and defined the limits within which work could be done. Still it might be hinted, that whilst municipal authorities were perfectly justified in counting the cost of sanitary reforms, they should also endeavour to form an estimate of the cost of sanitary—or rather unsanitary—neglect. If it could be fairly counted up, it would, in his opinion, prove the heavier burden of the two. The only difference was that every man hoped he might escape typhoid fever, cholera, or other pestilence, whilst no one was sanguine enough to hope that he might escape the rate-collector. Hence he preferred possible sickness and death to the certainty of an extra 3*d.* or 4*d.* in the £. He had spoken of the duties of certain professions in connection with the treatment of sewage; neither would he deny the right of men outside those professions to give the benefit of their experience, if such they possessed. But he regretted to find men who had no experience, beyond what might have been gained by a few flying visits to sewage works, expecting to be accepted as authorities. All were, surely, aware that the treatment of sewage required close, prolonged, practical attention. A man could no more decide, by reading reports and extracts, how sewage was to be treated, than he could learn from books how to direct an army in the field, or how to carry out large engineering works. How, without being familiar with all the facts of the case, could he know whether a plausible argument was well or ill founded?

In speaking of the different systems of sewage treatment, he always endeavoured to deal fairly with each. He had come to the conclusion that there was some good in every process, and that no one system could be sweepingly declared equally well adapted to all circumstances. There were cases where he should recommend irrigation; there were others where he should advise precipitation; and there were some where, from the standpoint of present knowledge, he should give a provisional adherence to "waste"—the running the sewage into the sea.

As a process which numbered many and most zealous—not to say occasionally intolerant—advocates, he would first refer to irrigation. No one could dispute that earth had a wonderful deodorising power, which increased the more finely the soil was pulverised and subdivided, and the more thoroughly it gave passage to the air. The fæcal matters and other impurities attached themselves to the surfaces of the particles of earth by a kind of cohesive attraction, and in this state were readily attacked by the

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oxygen of the air. Their organic carbon became carbonic acid; their nitrogen was converted into nitrous or nitric acid, which united with the lime, magnesia, and other basic matters present. Mechanically suspended impurities were arrested as by a sieve, and the water issued from beneath—not, indeed, fit for dietetic or domestic purposes, but at any rate in a fair state of purity, and quite inoffensive to the senses. But, whilst admitting that the soil had these powers of purification, when in an excessively fine state of division, and uniformly porous to a considerable depth, yet a shallow, rocky, or stony soil was of little value; moreover, with a dense clay the sewage was apt to form pools on the surface, and turn the land "sour," as farmers expressed it. In dry weather, too, a clay soil cracked, and, as the recent report of the Local Government Board admitted, let the sewage pass not even clarified. Now, to find soils suitable for effective irrigation at a convenient distance below a town was not always practicable. Many towns lay in a river valley, and to receive the sewage some situation must be sought lower down the valley. But the land in river valleys could rarely be had at a low cost, except it was liable to be flooded. Hence irrigation, whatever its advantages, and he was willing to admit they were many, could only be applicable to a small number of English towns—perhaps to not more than 5 per cent. It must also be remembered that there were few crops to which, according to the recent Report of the Local Government Board, constant applications of sewage were beneficial, or even safe: these were mangold-wurzels, cabbages, and especially Italian rye-grass. To potatoes, turnips, and white crops sewage must be applied with great caution, even in dry seasons.

As to Intermittent Downward Filtration, it had been rated by Mr. Bazalgette at its just value. It had all the disadvantages of irrigation, with scarcely any of its redeeming points.

The next method of dealing with sewage might best be described as "waste." Towns lying on the sea-shore were simply to carry their sewers out below low-water mark. When this could be done, the system—whatever might be thought of its ultimate results—had at any rate the merit of cheapness. In a land-locked bay, especially in warm climates—*e.g.* Sydney, Melbourne, Rio Janeiro, Bombay, Bahia, &c.—this process would assuredly, if carried out for any length of time, establish a perfect focus of pestilence. Towns situated on a river were sometimes recommended to adopt this system, carrying their sewage down in canals to a point below where the waters of the river were required for domestic or manufacturing use. But here this process began to be attended

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with difficulties. Whether or not to waste the sewage was one question, but to incur a heavy first cost and additional yearly expense in carrying out such waste was another.

But the waste process, like irrigation, was only applicable to a limited class of towns. What, therefore, was to be done with the remainder? Purification by chemical means, better known by the term "precipitation," was here a matter not of choice, but of necessity. And he did not see, if the matter was examined in the light of common sense, that the necessity should be considered very hard. It had been the evil of precipitation processes that they had been generally worked by joint-stock companies, the prices of whose shares were quoted on 'Change. These companies, engaged in a new and difficult business, had to feel their way, and it had been argued, from the scanty success of some of these companies, that the processes employed were inefficacious. Such reasoning was utterly fallacious. The efficacy of a chemical operation had no connection with the price of shares.

Admitting that in many cases chemical treatment—call it precipitation, though the word did not fully cover his meaning—was the only available expedient, the question next arose, What process was to be adopted? There was, in the first place, the lime process, either in its original state, or followed up by filtration (as at Bradford), or worked with the addition of small quantities of other substances. These processes expelled any ammonia existing as such in the water; they gave an alkaline deposit which readily became offensive, and without great care they yielded an alkaline effluent water. Now, it was well known that organic matter mixed with an alkali entered into putrefaction of a most offensive and dangerous character. If the effluent water from the lime process fell into a river containing mud rich in half-decomposed organic matter, all the conditions for a nuisance were ready at hand. True, when such an effluent had travelled for some distance, it would gradually be neutralised by the carbonic acid of the atmosphere. Still if a number of towns continually disgorged lime effluents into a stream, the general character of that stream would be offensive. In any sewage process it was important to keep the effluent water neutral, or even a little on the acid side. The lime process had, however, its legitimate sphere. In towns like Sheffield and Birmingham, where the sewage contained abundance of acid metallic salts, it might, if judiciously managed, produce excellent results.

Then there was a class of processes which depended on the application of a phosphate. Phosphate of lime was rendered soluble by

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an acid, was mixed with the sewage and then rendered insoluble by an alkali or alkaline earth, in the expectation that the impurities would be precipitated along with it. This was, to a great extent, the case, but there remained some formidable difficulties. Phosphate of lime when freshly precipitated was soluble to a decided extent in water containing carbonic acid, common salt, or sal-ammoniac. Now sewage contained these ingredients, and hence a quantity of the phosphate of lime remained in solution and flowed out with the effluent. But soluble, or even gelatinous phosphates, in contact with organic matter, had a wonderful power of setting up putrefaction and favouring the increase of low forms of life, such as the dreaded Bacteria. Hence, however well the water might be apparently purified, from a sanitary point of view any process which failed to remove the phosphates from the sewage, and, *a fortiori*, which put more phosphates in, could not prove satisfactory.

Next a number of processes made a more or less extensive use of the sulphates, or the chlorides of aluminium, or of iron. These were mixed in solution with the sewage, and a certain quantity of an alkali or alkaline earth—generally lime—was added, to neutralise the acid which was combined with the aluminium or iron, and rendered the precipitation more complete. It was a great mistake to deny the value of these processes. It was sometimes asserted that alum would indeed precipitate suspended organic matters, but was unable to effect such as were in solution. This was a singular error. Nearly the whole arts of dyeing—at least, wherever mordants were concerned—and of lake-colour making, depended upon the fact that alum and analogous bodies were capable of precipitating organic bodies from their solutions. Albumen was perfectly soluble in water, but was readily coagulated and precipitated by a solution, *e.g.* of sugar of lead. Or, if sewage were taken and filtered carefully, so as to remove all suspended solids, and then a few drops of a solution of alum added, a turbidity in the liquid was soon perceived, which condensed and settled to the bottom as a precipitate composed of alumina combined with organic matter. The earthy and metallic salts just mentioned were not all equally adapted for the treatment of sewage. Salts of iron were apt to leave in the watercourses a yellow deposit of hydrated oxide of iron, which was suspected by outsiders to be of excrementitious origin. If sulphate of iron was used, the precipitate, after a time, was liable to give off sulphuretted hydrogen.

In the "sulphate of alumina and lime process," the effluent might be neutral if the lime was used merely to neutralise the

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acid of the sulphate of alumina. But if it was used in aid of the sulphate of alumina, as a substantive precipitant, the deposit would be alkaline, and the effluent probably also, thus being open to the objections already raised against the lime process. A further drawback to the processes just mentioned was that the sediment, being light, was apt to rise to the surface of the water. Something was therefore required which should act as ballast. Besides, with the salts of aluminium and iron the work of purification was not complete. Something was wanted to absorb the sewage gases into its pores.

The action of irrigation lands and filters depended greatly on the fact, that the impurities appeared to be attracted out of the water, if a sufficient extent of finely divided matter, sand, clay, or charcoal, as the case might be, was presented to them, and thus the waters were to a certain extent purified. A little experiment would show that this end might be effected in two ways. If sewage was filtered over a quantity of charcoal and clay, the smell would be removed. Or, if the charcoal and clay were shaken up with the sewage in a bottle, the smell would be taken away. But if this experiment was tried on a few thousand gallons of sewage in a tank, the impurities, though deposited on the surface of the fine particles of clay and charcoal, still remained suspended. The mixture did not subside.

Here, now, were two imperfect processes; on the one hand, sulphate of alumina, or some analogous salt which clarified but did not perfectly deodorise, and gave a precipitate which was apt to rise up; on the other hand, clay and charcoal, which deodorised but did not clarify, and which, *per se*, remained floating in the water with their cargo of impurities. But put these two classes of bodies together and combine their action, and the "sensational" A B C process resulted. The charcoal would deodorise, and the finely divided clay would absorb impurities, and both substances being brought to bear in a state of exceedingly fine subdivision, every pound of the mixture offered acres of surface. The Author had quoted, from the Report of the Rivers Pollution Commissioners, certain objections to the A B C process, which he said were "based upon irrefragable evidence" (*ante*, p. 112). These statements were that:—"1. On no occasion has the purification been sufficiently complete to render the effluent admissible into running water: 2. The effluent is little better than what can be obtained by mere subsidence: 3. The manure has a low market value and cannot repay the cost of production: 4. The manipulations incident to the process are nauseous and offensive."

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Now admitting, as he was willing to do, that these charges might have had some show of truth at the time and for the place to which they referred, he gave them a most unqualified denial as far as the present time was concerned. The purification of the water was pronounced satisfactory by Mr. Keates in his report on the experiment performed at Crossness in the autumn of 1872. Mr. Keates also mentioned the important circumstance, that the effluent channel at Crossness, though left, at his special request, unswept for nearly two months, did not exhibit the slightest trace of sewage fungus. It was curious that Mr. Bazalgette, who evidently had made use of Mr. Keates's report, should have overlooked this fact, or should have considered it unworthy of mention. The effluent taken by the officials of the Leeds Corporation during a week's special trial in September 1875, conducted without the presence or even the knowledge of the Native Guano Company or any of its officials, was found, according to Dr. Letheby's analysis, to fulfil the requirements of the Rivers Pollution Commission and of the Thames Conservancy.

As to the second and the fourth charges, they were almost too absurd even for contradiction. That in the face of the evidence which had appeared on the other side they could still be believed and retailed without examination was strange. Mr. Keates, in his report before referred to, expressly stated that the process from beginning to end was free from nuisance. At the Leeds Sewage Works the authorities had uniformly declared the A B C process to be entirely free from offence; and their experience with this process could scarcely be called imperfect or experimental, for by it had been treated nearly 5,000,000,000 gallons of sewage, without a single complaint of nuisance, and with the production of an effluent fit to run into any ordinary river. The experiment of allowing a tankful of sewage to subside without the aid of chemicals was tried by the Leeds sanitary authorities in 1873, and the result showed that the second objection was simply ridiculous.

He now passed to the third objection—the manurial value of the "native guano," and the cost at which it was produced. Without the least desire to speak disparagingly of his own special science, he was bound to disregard chemical evidence against a manure, when there was overwhelming practical evidence of its value. He attached little importance to a chemical analysis of manure when it simply gave so much per cent. nitrogen, and so much per cent. phosphoric acid. The nitrogen, the analyst said, he calculated as ammonia, not saying whether it really was in a form that would nourish a plant or be rejected by it; and the phos-

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phoric acid he calculated as bone-ash, not saying whether it was in a form which the plant could take up, or whether in a form which had little, if any, manurial value. Just as mere chemical analysis would utterly condemn water containing Liebig's extract, infusion of tea, or bitter ale, as largely contaminated with nitrogenous organic matter or albumenoid ammonia; so the chemist, by taking a fictitious standard for manures, and judging only by the percentage of two of the many necessary constituents of the food of plants, gave an arbitrary money value to a manure which was often different to the price it fetched in the market. It was, of course, evident that the value of the native guano depended in a great measure on the kind of sewage from which it was obtained. The sewage from a residential city containing no manufactories would be likely to make better manure than that from Leeds, which did not contain much night-soil, but was full of manufacturing refuse, dye waters, and things of that sort. The native guano made at Crossness produced wonderfully good crops when applied on land adjoining the Metropolitan pumping station, and under the strict supervision of the officers of the Metropolitan Board of Works. Dr. Frankland took a sample of the Leamington deposit, and after drying it found that it contained about 2¼ per cent. of ammonia. Samples of native guano, prepared under his own eye, from Paris sewage, at experimental works at Gennevilliers, were sent to M. Terreil, one of the first analytical chemists in France, and were reported by him to be worth in their dry state 108·6 francs per ton, or when reduced by the normal amount of moisture present in "native guano" to 87 francs, or £3 12*s.* 5*d.* per ton. But as regarded the value of a manure, facts were worth more than theories. The great test was, What would it fetch in the market? The Native Guano Company had sold over 4,000 tons of their product, which had brought in about £14,000 in hard cash, or about £3 10*s.* a ton, and the majority of the purchasers had expressed themselves satisfied with the results. These favourable opinions had been given by practical men, farmers and market-gardeners, not interested in the success of any company, and assuredly caring nothing about sewage schemes, but honest enough to admit facts placed before them.

The Author next maintained, most fallaciously, that by the A B C process "purification can only be purchased at the sacrifice of solvency," and that "the two results of profit, or even solvency, and purification, are inconsistent and incompatible" (*ante*, p. 113). It was, perhaps, scarcely consistent with his foregoing remarks that he should admit the possibility of purification by precipitation at

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all. It was also well to remember, with reference to profit, that Mr. Bazalgette pronounced that "no profit must be expected from the cultivation of crops" on an irrigation farm (*ante*, p. 158), and that he approved of running the sewage into the sea, where any return was out of the question. But leaving these points aside, look at the figures of the Crossness report. The assertion was made that it cost £6 6*s.* 4*d.* per ton to produce a manure worth only £1. How were those figures obtained? It would scarcely be believed, yet it was the fact, that the Metropolitan Board of Works insisted on debiting the process with the salary of a chemist who, during the three months' official trial, went down daily to Crossness to see the sampling performed, and to take counter samples on behalf of the Native Guano Company! Yet no one could contend that the services of such a chemist would form part of the ordinary working of the process. Again, every man of business knew that sulphate of alumina could be bought much cheaper on the large scale, under contract, than on the small scale. For the sulphate of alumina employed at Crossness the Native Guano Company paid £8 5*s.* per ton. But if a large constant supply were wanted, then the largest alum manufacturers in the world had offered to supply the same article at £3 15*s.* per ton. Since that time the price of sulphate of alumina had been brought even lower. Further, it was well known that in the autumn of 1872 the price of coal was about double its normal figure, being at Crossness £1 10*s.* per ton. The total expense of £914 incurred in the three months' trial at Crossness was thus a mere fancy figure, and threw no light whatever on the true average cost of working the process. But he might go further. Every engineer knew that the construction of a series of tanks and channels, so that light suspended matter might subside in them as rapidly and as completely as possible, was a problem of no little difficulty. The depth, width, and length of the tanks, the inclination of the sides, the proportion of the tanks to the volume of the water to travel through them in a given time, all affected the result. Now at Crossness this problem was imperfectly dealt with. The current underwent frequent turns at a right angle, and at each of these a rotatory movement was set up, which raised the precipitate to the surface. To overcome this an excess of chemicals had to be used, so that the precipitate might fall more rapidly and more heavily. Hence an extravagant consumption of materials. Parenthetically, he might remark that one of the most important contributions which an engineer could bring towards the solution of the sewage question was an investigation into the circumstances under-

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which suspended bodies might be brought to subside, and into the causes which delayed or prevented such subsidence.

The accuracy of what he advanced was confirmed by the results of the experiments made in September 1875 by the Leeds Corporation. Whilst the water was purified by the A B C process so as to come within the recommendations of the Rivers Pollution Commission, the working cost was merely in the proportion of £13,000 yearly, equal to a rate of 3¼*d.* in the £. This included labour, fuel, and all other charges, in addition to the £8,000 required for chemicals alone. At this cost, then, the entire sewage of Leeds, a town of 285,000 inhabitants, was actually treated. These particulars had been fully stated in a pamphlet by Mr. Morant, the Borough Engineer. Yet it must be remembered that the sewage of Leeds was exceptionally difficult to treat, on account of the residual dye-liquors, which required a large consumption of sulphate of alumina. It was also asserted that it was impossible to dry the mud from a precipitation process at less than £1 8*s.* 9*d.* per ton. Now sewage mud had actually been dried at Leeds in Borwick's cylinders at about 5*s.* per ton. This statement was made by Mr. Alderman Tatham, and was based upon the actual figures in the books of the Sewage Committee of the Leeds Town Council. The Universal Charcoal Company quoted the cost as 5*s.* to 6*s.* per ton of dried manure. The manure produced at Leeds was estimated at 20,000 tons yearly. Supposing this to be sold at the contract price, "wholly inadequate to defray the cost of treatment," (*ante*, p. 115), as Mr. Bazalgette called it, of 12*s.* per ton. Here, then, was an income of £12,000 per annum, leaving a total yearly loss of only £1,000. Now, by way of comparison with Tunbridge Wells, a population of 23,000, in disposing of their sewage by irrigation, submitted to a net yearly loss of £5,900. Were Leeds, with its 285,000 inhabitants, as extravagant, it would have had to pay £1,000,000 for its sewage works, and £70,000 yearly loss on the operations. The cost in 1875 for wasting the sewage of London was £59,000. But London, large as it was, was not sixty, but only, say, twenty times as large as Leeds. "The experience also at Hastings, Southampton, Bolton, and Leeds," said Mr. Bazalgette, "all tends to point to the same conclusions" (*ante*, p. 114). He would possibly be surprised to learn that at Southampton there never was any experience at all, as not 1 gallon of sewage had been ever treated there by the A B C process! At Bolton the A B C process was discontinued by the Corporation, not as inefficient, or as too costly *pro ratâ*, but because the low standard of purity there needed could be reached by a cheaper process.

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At Hastings there was no objection to the purity of the effluent, and no difficulty in disposing of the manure at a high price. It was curious that if sewage works failed commercially from mismanagement, from disputes, or from any cause whatsoever, the blame was always laid on the inefficacy of the process.

The Author's views on precipitation processes, were they well founded, would be formidable. But his information on the subject was neither comprehensive nor accurate. The authorities he selected were not always trustworthy, and he had evidently no experience of his own to warn him where they were astray. He gave not the evidence of his own senses, or the result of his own observations and experiments, but mere hearsay, second-hand testimony. He brought forward no facts with which sanitary engineers were not perfectly familiar, no arguments which had not already been weighed. He condemned precipitation utterly; he damned irrigation with faint praise; he rejected Liernurism, and limited the dry closet system to small hamlets and detached buildings. But he had evidently a leaning to that gigantic system of waste against which Liebig argued with such power and perseverance. For whether the sewage of London was let flow into the Thames along its course, or was intercepted and discharged at Crossness and at Barking Creek, the loss of plant-food—of the elements of fertility and human life—was no less culpable. The more widely this system was extended, so as to return to the sea what had been taken from the land, the more surely and quickly would the finite stock of phosphates, of potash, of nitrogen compounds present in the soils of the world, be exhausted. Let it be remembered that the animal and the plant created nothing. There was nothing in bread or in beef which was not taken from the soil, and unless all were returned to the soil that had been taken from it its fertility must ultimately be exhausted. When agriculturists applied to the land nitrogenous compounds, mineral phosphates, and Stassfurth salts, they were drawing on the earth's capital, and their drafts would not always be honoured. One ton of atmospheric nitrogen was worth in the free state nothing, but solidified in the form of nitrates or ammonia it was worth £100. The store of nitrogen in the atmosphere was immense, but in its free, gaseous state it was not available either for the food of plants or for technological or warlike purposes, and was only rendered assimilable by natural processes of extreme slowness. Were the whole of the sewage to be discharged into the sea, the supply of fixed nitrogen could not stand the drain very long. The population of the United Kingdom alone would waste, at the rate of

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½ ounce per head, 445 tons daily, the market value of which was £44,500, or, yearly, £16,000,000. If, then, the community continued to waste the supply of available nitrogen, the time might come when there would be neither bread nor beef—and not even gunpowder!

Lieut.-Col. JONES, V.C., thought it could hardly be maintained that there had been little discovery or invention with regard to sewage during the last quarter of a century, when the chaos of systems and creeds prevailing ten years ago was contrasted with the Paper, running parallel as it did with the excellent Blue Book on sewage disposal, and the Report of the Council of the Society of Arts, after an inquiry which had led to much the same conclusions as those stated by the Author. Mr. Bazalgette had asked the question whether sewage could be applied to land at an agricultural profit. Considering the difficulties of sewage farming as compared, not only with other farming but with other pursuits, it could hardly be expected that a casual shifting committee of a local board was likely to succeed in that kind of work; and it would be found that the majority of experiments in sewage farming had been carried on in that shiftless manner. Where, however, sewage farms had been undertaken by persons working for their own interest—as in the cases of Mr. Blackburn at Aldershot, the Earl of Warwick at Leamington, and Mr. Brundell at Doncaster, some degree of agricultural success had been achieved. The results of his own experiments at Wrexham, which had been going on for five years, had been pretty widely published, from year to year, in detail. The fifth year had only just ended, and he was not, therefore, prepared with the same detail in regard to it as the others; but his cash book and stock-taking afforded a sufficient proof that the profit of the year (which had been a most unfavourable one), after allowing interest for capital and instalments to pay off the improvements within the term of his lease, would exceed the average of the four preceding years, and represented a fair farming profit. He paid a rent of £5 for every acre under crop (with the exception of 20 acres which he had himself added to the Corporation farm), including rates and taxes and the sewage; and under these circumstances he thought it was something to say that any profit had been gained. He had arrived at the conclusion that wherever sewage was brought to the highest point of any suitable land—and he considered that it ought to be brought there by the sanitary authority for its own purposes—any intelligent farmer, who could acquire a little engineering know-

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ledge, the use of the level and staff being sufficient, might apply the sewage economically to the whole of his land, and recoup himself for the expense in a considerable lease. The inference to be drawn from the Paper, and from various reports, was that no agricultural profit could be expected. He agreed that a town requiring to have its sewage disposed of could never expect a profit under present circumstances, but a farmer might reap sufficient profit to make it worth his while to take the sewage. He would, in fact, have a better profit than he could possibly get by any other application of his capital to the same land in the same time. Mr. Bazalgette had inquired whether the application of plain water would not be equally efficacious with sewage. Part of the land rented by him was commanded by a brook with a mill-race of fresh water, and he constantly applied the water side by side with sewage on the same land; the result, however, was much in favour of the sewage. With regard to Intermittent Downward Filtration, when he first took his farms at Wrexham he was assured on every hand that the land was saturated with sewage, and that he could do nothing with it, that the grass was rank and the cattle would not eat it; in short, that everything was at the worst. One of the first things he did was to go to Merthyr Tydvil to see the works established there. He returned, and under the impression of the excessive amount and strength of the sewage he was to have, he laid out separate portions of land as a safety valve for Intermittent Downward Filtration, with 6 feet depth of drainage, digging the surface over at great expense. During the first season, the greater part of land being under hay crop, he was glad to use the 3 acres set aside. For about a week he used them intermittently, by day on one area and by night on the other; but since that time he had never used them as a safety valve. About two years ago Mr. Bailey Denton wrote expressing sorrow that he was not still using the intermittent filtration area. He replied that it was not worth while to waste the sewage for the purpose of keeping up an example of intermittent downward filtration. He had found the same thing at Doncaster, where 5 acres had been prepared for intermittent downward filtration as a safety valve, but had never been used. He agreed that it was foolish to have artificial drainage, which was subject to many casualties, when natural drainage was available. In sewage farming everything depended upon alternate periods of aeration and saturation with water, without which there would simply be a sewage marsh. He had tried sewage sludge side by side with farmyard manure for

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the last five years, and with about 60 per cent. of moisture it was, bulk for bulk, rather superior to the manure. The farmers were glad to give 1*s.* or 1*s.* 6*d.* a ton for it; but by leaving it to dry they lost a great deal of its valuable qualities. Dr. Voelcker had taken the right standard in arriving at the actual commercial value of sewage sludge. He deduced the theoretical value from the chemical properties, and arrived at the commercial value in the same way as with farmyard manure. If the sewage sludge could be dried, as it had been in some of the samples analysed, the highest of the practical values was about 10*s.* a ton; but Dr. Voelcker stated that the actual cost of drying so as to make it into a portable manure was 30*s.* a ton. He thought that was an excessive amount. He had, on behalf of a company, undertaken some experiments in drying sludge, in order to ascertain the price, and hoped soon to arrive at accurate details which were now wanting. It was evident that if the sludge was only worth 10*s.* a ton when dry, very little could be afforded for the process, unless in those exceptional cases where a town found it so difficult to get rid of the sludge that it was willing to pay to have it disposed of. The great point now was, seeing that sewage was regarded as a thing to be got rid of, to have no more than was necessary. But rainfall was taken from the roofs and the streets, comparatively clean water that might go straight to the rivers, and was poured into the sewers, to the great embarrassment not only of sewage farmers but of precipitationists. He had often asked precipitationists what they did when rainstorms occurred; and the reply was, "We draw the floodgates and let it all go;" and every honest sewage farmer would say the same, unless he had the protection provided at Wrexham in the shape of fixed storm overflows, which took effect at a given moment. No practical man would care to deal with unknown and ungovernable quantities; but if he knew approximately what amount he would receive, he would know how to deal with it. He did not advocate a crotchet and insist upon a duplicate system of sewers, complicating the matter by the necessity of watching every spout; but he would point to such recent examples as those of Oxford and Reading. The sewage flowing from Reading amounted to 17 gallons per day per head, with a water supply of 20 gallons, showing that the sewers certainly took in little or no rain or subsoil water. That, he believed, was the question of the future for sewage. Colonel Jones added, that the soil of his farm was a nice loam upon gravel.

Mr. C. E. Austin agreed with all the conclusions arrived at by the Author except the last, but he considered that turning the

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contents of the sewers of towns into the sea was a clumsy makeshift, only so far successful that it transferred a part of the nuisance to some other locality, generally at a considerable expense, and certainly at an extravagant waste of that which ought to belong to the soil. If the whole of Great Britain were to throw all its sewage into the sea, it would cast away 2,000,000 cubic yards of solid matter annually, and it would require at least 1,500,000 tons of imports in excess of its exports to keep it above water. Such a town as Brighton, for instance, containing, say, a population of 100,000, would produce as much as 5,300 cubic yards of solid house sewage per annum, besides 950 cubic yards of minutely divided grease with what, for want of a better name, he called precipitated carbon; in all about 6,250 cubic yards, exclusive of the refuse of breweries and manufactories, and road dirt. At least 4,000 cubic yards of this house sewage remained undissolved until decomposed, and would float on the salt water, and eventually be deposited on the shore of some neighbouring locality, where it would produce fungi, and on decomposition would with the 2,250 cubic yards of soluble matter aid in the growth of other cryptogams, such as sponge and seaweed, and an accumulation of seaweed was well known to be an unpleasant thing on the coast. The consequences in this temperate climate would not be so soon felt as they might be in a hotter place; but along the shores of the Mediterranean and the Black Sea, wherever a Roman town was formerly situated, ague and fever reigned without intermission. He might instance Rome and its Cloaca Maxima and the Pontine Marshes; Samsoon, on the Black Sea, with its salt marshes composed almost entirely of ancient town refuse; Ephesus with its silted-up port, and Smyrna with its alternating beds of oyster-shells and town refuse. Smyrna still discharged its sulliage into the sea, but it did not affect the town so much as the opposite side of the bay, where the odour was overpowering from the solid matter which had been deposited on the shore. Circumstances did not generally allow a steep gradient to be given to the long conduits which conveyed the refuse to the sea. A great deal of the solid matter was deposited in them, and they became elongated cesspools, and must be constantly cleansed, at considerable expense. Then the slush must be got rid of somehow. Was it not better to get rid of the whole of the solid matter at once? It would not cost any more, nor be a greater nuisance. It should never enter the main sewers. This objection held good to all long conduits with flat gradients, whether for combined systems with irrigation—which was taking one man's nuisance to his neighbour's field—or for leading the

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sulliage to chemical works. He had held the same opinion for eleven years, that the solids should be separated from the fluids before any portion was dissolved or allowed to enter the main sewers, and that the solids should be got rid of otherwise. They were easily utilised, without the smallest nuisance, by trenching into the soil when fresh. He had tried this for years in a town on the coast; and he found the solids occupied so small a compass, that the annual amount discharged from houses containing a population of 10,000 could be trenched in profitably on ¼ acre. He could affirm that the effluent from dwelling-houses if properly strained, when it was fresh, and the strainings extracted once every twenty-four hours, would not contain more than 8 grains of nitrogen and carbon per gallon, although by analysis the fluid secretions alone furnished 12 grains per gallon, allowing 30 gallons per person. When only 8 grains of fresh organic matter per gallon had to be dealt with, it was no longer difficult to dispose of the effluent. In the first place the emanations from it in its fresh state were innocuous; and that he thought Dr. Frankland would confirm, for he had seen a statement of both his and Dr. Letheby's from which such an inference might be drawn.[1] It might be exposed in open paved ditches and carried to a convenient place to be purified, if it wanted further purification. Secondly, so small a quantity of organic matter was easily absorbed by suitable plants. Next with regard to irrigation, in times of flood, such as during the late Thames inundation, the sewers would never be emptied by the pumps, but the flood would be carried, as it were, to the irrigation ground, and, as Colonel Jones had said, there must be an overflow, which should be so regulated as to limit the quantity of fluid upon the crops. The overflow filled the ditches in the neighbourhood, carried with it a quantity of fibrin and other solid refuse, and, when the flood subsided, transferred the nuisance to the neighbourhood of the irrigation ground, causing malaria and deleterious odours. In this country land plants were not well adapted for irrigation, because when too much watered they were apt to decay and produce noxious malaria. Water plants were the natural absorbents of

[1] "I have ascertained by repeated experiments that when the clear liquid of common sewage is exposed to the air it quickly absorbs oxygen and loses its offensive odour. It is the insoluble organic matter which keeps up the putrefaction and evolves the noxious gases."—Report to the Hon. Commissioners of Sewers of the City of London on Sewers and Sewer Gases, by Henry Letheby, M.B., &c., p. 72.

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the organic matter of sulliage; as, for example, the Anacharis which, he believed, was called the sewage weed, and which appeared in rivers when they became polluted with sulliage, and when the drains were diverted from the watercourses it either wholly, or almost wholly, disappeared. One square foot planted with Anacharis in water 2 feet 6 inches deep would absorb, in average weather, 80 grains per day; 9,000 square feet of such a plantation would purify sufficiently 100,000 cubic feet of effluent per day; or 1 acre would suffice to purify 500,000 cubic feet, which was equal to the discharge of a population of 100,000. Many other plants would absorb almost as much organic matter, such as Limnaceæ (duckweed), Cyperaceæ (sedges), Phragmites communis (common reed), Butomus umbellatus (flowering rush), white and yellow lilies, Hydrocharis morsusranæ (frogbit), water ranunculus, Sagittaria sagittifolia (so common in the Thames), Marchantea, liverwort, and, lastly, watercress, which was a profitable crop. The space required for purifying an inodorous effluent containing only 8 grains of organic matter to the gallon could be found almost anywhere amongst the villages and hamlets bordering the Thames, and for every village separately when a little prejudice was overcome, which it was the business of the scientific world to remove. The inodorous effluent when required could be conducted in paved ditches, at a cost of 7*s.* per yard, to any convenient spot. Long sewers and pumping would thus be dispensed with, and a great reduction in the cost of construction effected. In conclusion, he would observe, that the purification of the larger rivers could be, in a great measure, accomplished by separating the banks (where possible) from the land by ditches containing aquatic plants, which should be cut down at the commencement of the cold season. Into these ditches all the land water would pass, and become much purified before flowing into the rivers. The plants would act as a strainer, and if a floating bar were placed at the outlet it would catch the matter not intercepted by the plants. It was well known that the water in the Thames was generally purest at the end of the warm weather in autumn before the weeds began to decay. By that time they had absorbed nearly all the organic matter from the water. If the Thames Conservators would then have them cut down and applied to some useful purpose, much less would be heard of the impurity of the river above the waterworks' intakes.

Mr. W. Hope, V.C., desired to correct the statement with regard to the scheme which he had prepared, in conjunction with Mr.

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Hawksley, for Birmingham. The Author appeared to imagine that it was proposed that the same quantity of sewage per acre should go on to the land at Birmingham as Mr. Bailey Denton thought had been accomplished at Merthyr Tydvil. There never was any such idea. The proposal was 440 persons per acre; but the land selected was merely a filter bed at the end of a long sewer from which the sewage would have been discharged right and left to the different farms along the road; consequently, in many seasons of the year, a comparatively small amount of sewage would have reached the filter bed. There were some mistakes in the Paper, which it was desirable should be corrected. For instance, it was stated that the nitrogen in sewage did not appear to be susceptible of conversion into vegetation. A Committee of the British Association took the subject into consideration for seven or eight years, and had published tables showing the results obtained on Mr. Hope's farm at Romford. It was said that Dr. Frankland had found nearly 70 per cent. of the nitrogen originally in the sewage escaping in the effluent water from the Lodge farm at Barking. He had no doubt of it, because in that case they purposely wasted the sewage. On his farm at Romford over a whole year only 10·67 per cent. escaped in the effluent water It ought to be remembered that it was not possible, even in the most careful laboratory experiments with flower-pots, to convert the whole, or anything like the whole, of the nitrogen applied, into vegetation. It was a mysterious process, not yet thoroughly understood. From one-third to one-half was all that had ever been obtained; and on his farm he had actually converted about one-third. He had, therefore, proved that the nitrogen obtained as in sewage had the same agricultural value, if properly and intelligently applied, as the nitrogen existing in farmyard manure, guano, or any other kind of manure. With regard to the question of value, he would read an extract from a letter written by Mr. Morton, in November 1866:— "We are at this moment getting about 2*s*. 6*d*. a day for each cow for 7*d*. worth of grain, 5*d*. worth of hay, 3*d*. worth of attendance, and 1 cwt. of grass; and each ton of grass consumed in our cow-houses is yielding 25*s*. in milk." He might add that, on his own land, he had cut 80 tons of grass off 1 acre of land in twelve consecutive months. In producing that grass there was no waste of nitrogen, but as much was converted as could be expected to be converted from any manure. It followed that the value, said to be "theoretically" placed by the chemist on human excreta, was really practical. As to the profits of sewage farming, he was not aware of a single case in which a town farming land itself had made a profit;

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but, on the other hand, he was not aware of a single case, except his own, where an individual farmer had not made a profit. In his case the explanation was simple. He had contracted for the sewage of 8,000 animals, and had only received the sewage of 3,000. The Author was wrong in supposing that carbonate of ammonia, in solution in sewage, could ever evaporate. It had a greater affinity for water than for the atmosphere; and it was therefore impossible to evaporate it into the atmosphere. With regard to the commonly received idea that sewage-grown produce was unwholesome, he could support all that had been stated by the late Mr. Smee about the improper application of sewage to any kind of crop, and the danger of intestinal diseases from that source; but when the sewage was properly applied, there was absolutely no danger to either man or beast. He had himself fed an ox of his own breeding exclusively upon the refuse of his farm for twenty-two months, and then, in the presence of Dr. Cobbold and various surgeons and chemists of eminence, the animal was dissected, and no trace of disease was found. The animal had been carefully watered from the house well, and not from the horse-pond, which was the source of much disease. He had invested in a herd of pedigree short-horns, and last year he had taken a first prize for one of the three-year-old heifers bred on the farm; so that it was evident there was nothing unwholesome in the feeding.

In conclusion he would venture to draw attention to the fact that there was unquestionably, at times, a slight odour perceptible in the immediate vicinity of the outfall sewers into the Thames. A few years ago there was an outbreak of scarlet fever, which spread through a great part of London, having its origin, he believed, at Barking. At all events, the death-rate in that unfortunate town was over 60 per 1,000 in one quarter. It was a common mistake to suppose that Parliament had ever sanctioned, or that Sir Joseph Bazalgette had ever designed, the outfalls for the permanent disposal of the sewage of London. Sir Joseph and Parliament had looked forward to the sewage being carried to a greater distance from London, and, if possible, utilised. The fact that it had not been utilised according to the scheme for which Mr. Hope had obtained Parliamentary sanction was now the subject of a suit in Chancery, and he would not therefore discuss it. He would merely say, that the statements put forward as to the scheme not having answered were entirely untrue; that the scheme had not been carried out; that it had never had a fair chance; and that it had been throttled.

Mr. Bailey Denton expressed, through the Secretary, regret

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that the Author should have addressed to the Institution statements in which the opinions of others were distorted, while the most important features of the cases criticised were omitted, especially in regard to the Intermittent Filtration works at Merthyr Tydvil and at Kendal. Passing by many minor misrepresentations, he might remark that, having devoted the greater part of his life to improvements of land, with a view to increase the produce of the country, he should be the last to advance opinions so detrimental to agriculture as the Author had attributed to him, for the purpose of making capital out of what Mr. Bazalgette was pleased to represent as an experiment. So far from this treatment of the subject being correct, he regarded the appropriate application of Dr. Frankland's theory of Intermittent Filtration of sewage through natural soil as one of the greatest boons to agriculture—not simply as a means of getting rid of a troublesome matter, but as a means of adding to the food produce of the country. He did not suggest that the country should generally adopt Intermittent Filtration, *per se*, in its extreme form, but in such modified or combined shape as would meet the circumstances of each case. Under favourable conditions the view that 1 acre of suitable soil would cleanse the sewage of 3,300 people could be verified, though it might never be necessary to go to such an extreme. To secure permanency, Mr. Bailey Denton had recommended treble this area, as a minimum, or say 1 acre to 1,000 persons. Practically it was seldom necessary to adopt even so low a minimum as that. He was now carrying out works in different parts of England, all of which aimed at the perfect cleansing of the sewage and increased produce of vegetation by the application of sewage to land, where different proportions of land to population ruled, although in only one instance had the narrowest limits been adopted, and in each case Intermittent Downward Filtration formed a part of the operations. As the Author had admitted that 1 acre would cleanse the sewage of 500 or 600 persons, it was unnecessary to discuss what should be the exact proportion of persons to land, particularly as the figures must vary with soil, depth of drainage, and other circumstances. In truth, he was quite content with all the "conclusions" arrived at by the Author except one, though he rejected *in toto* the means by which they had been arrived at.

The conditions essential to success were that (1) the ground should be appropriately drained, (2) the areas carefully formed, and (3) the sewage applied intermittently with scrupulous attention. Intensified Irrigation was only a learned term for bad

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sewage farming. Having farmed somewhat largely, and being a sewage farmer at the present time, he felt assured that sewage could not be constantly cleansed, nor a satisfactory return obtained from its utilisation, so long as the farmer was obliged to take the sewage at all times and under all conditions; and he did not hesitate to affirm that no sewage farm could be made to perform those duties, unless a comparatively small area were laid out for Intermittent Filtration, to be held by the sanitary authority itself to insure the perfect cleansing of the sewage, and not placed in the hands of the tenant of the remainder of the land.

The facts as regarded Merthyr might be briefly stated thus:— Having been called in by the Lords Justices of Appeal in Chancery to devise a means of preventing temporarily the pollution of the river Taff, he adopted Dr. Frankland's suggestion of Intermittent Filtration, and rejected, on the strength of his own experience in land drainage, the drawbacks Dr. Frankland himself associated with the process. The works ordered to be executed upon his report had been carried out originally by Mr. Harpur, the local surveyor. They were, however, done in such a manner that he was required by the Lords Justices to take them into his own hands. It was when thus obliged to act that the Local Board of Merthyr, at a meeting called to ascertain his views, authorized him so to carry out the temporary works that they should afterwards act as a permanent "safety valve" for the irrigation farm of 375 acres which the Local Board were then laying out. It was to this fact that the chairman, Mr. Jones, referred, in the expression quoted by the Author, to the effect that "the Board contemplates no abandonment of the filtration areas, but looks upon them as a 'safety-valve'" (*ante*, p. 142) for the irrigation lands—which was exactly what was intended from the first. The thorough success of Intermittent Filtration, as demonstrated at Merthyr, did not depend upon what had been done with the areas since they ceased to receive the whole of the sewage. The analyses of Dr. Frankland in 1871 and 1872, those of Dr. Russell in the summer and winter of 1872, and those of Dr. Benjamin Paul in 1871 were sufficient to prove this, when considered in connection with the results at Kendal. The average of these analyses showed 0·016 of organic nitrogen in 100,000 parts of effluent ·id. As to the quantity of sewage cleansed when the analyses › made, the dry-weather outflow of the sewers varied from a mum of 700,000 gallons to upwards of 1,000,000, increased ng wet weather to 2,000,000 gallons. These ascertained quan-

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tities conveyed much more information than any estimate of the number of persons contributing the sewage; though under the conditions prevailing at Merthyr, they might fairly be considered to represent the sewage of 30,000 persons. But perhaps the most telling proof of the sufficiency of the works was to be gained from the words of Mr. Jones, who said that "so satisfied is the Merthyr Board with the principle of Downward Filtration as the purifier of a large quantity of sewage on a small area, that Mr. Harpur has just designed works for the disposal of the sewage of a population outside our main drainage according to that principle, and we are seeking for powers under a provisional order to obtain land compulsorily for that object." Why did the Author omit those words? The confidence in the process existing at Merthyr had been further evinced by Mr. Harpur, who wrote to Mr. Denton some time previously to the statement made by Mr. Jones: "You know my objections to your Merthyr scheme were due chiefly to its interference in some measure with my plans; but all that is past, and having carefully watched the process of sewage filtration in operation here, and observed its remarkable success, I should be fostering a prejudice if I hesitated to give evidence in its favour." "I am satisfied that where land for irrigation is expensive or difficult of access, filtration is the proper thing."

Leaving the Author to raise doubts and difficulties as to the exact proportion of population to land, while declaring his own "conclusion" to be that the process might be resorted to when land was difficult to obtain (which was all that Mr. Denton had ever advanced), if the number of persons contributing the sewage did not exceed 600 (instead of 1,000, as suggested by him), he would remark that the important question was, not whether the number of persons should be 600 or 1,000 to the acre, but how the different modes of treating sewage affected the ratepayers, always assuming that the rivers were relieved of pollution. The following facts as to Merthyr met this part of the question in a decisive manner. The return from the crops raised during the first year from the 20 acres laid out for Intermittent Filtration, while they were cleansing the whole of the sewage discharged from the Merthyr district, reached £20 an acre, and the same average return had been obtained from the 55 acres of land immediately adjoining the 20 acres. If instead of extending the application of the sewage to the additional 300 acres at a distance, now prepared to receive it, the works had stopped with the 20 acres of filtration and 55 acres of irrigation, the ratepayers.

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at Merthyr would have obtained a return more than sufficient to cover the cost of the 75 acres of land and the whole of the works connected with the 75 acres. From the best information he could collect, the actual outlay for works on the 75 acres had been £6,000. That sum covered the delivery conduit and the preparation for both filtration and irrigation. Seeing that the cost of the preparation for filtration was greatly increased by the circumstance referred to, it might be assumed that the whole 75 acres could have been laid out for Intermittent Filtration for the same sum that had been expended on the combined arrangement. Now the sum of £6,000 at 6 per cent., to repay the principal with interest, was equal to £360 per annum, and the rent or annual charge for the 75 acres of land, he was informed, did not exceed £380. It followed, therefore, that the yearly charge upon the district for both land and preparation amounted at this moment to about £740, or nearly £10 an acre; so that if the return from the crops on the 75 acres should still amount to £20 an acre, and the current expenditure to no more than £10 an acre (which was ample), there need be no charge whatever upon the ratepayers of Merthyr for the disposal of their sewage. What was the actual state of things? The annual charge, to repay the cost of the 375 acres, amounted to about £3,500 a year, necessitating a rate of 6½*d.* in the £, irrespective of any loss which attended the farming of the 375 acres instead of the 75 acres, and the loss on sewage farming always increased as the area increased beyond the demands of the locality for sewage products. These figures were those given in the recent report of the committee appointed by the Local Government Board, and it might fairly be asked why the actual effect upon the ratepayers had not been referred to, seeing that the report, as the Author stated, was issued in December last.

The facts with regard to Kendal had been even more distorted than those of Merthyr. The "sewage proper" of the town (400,000 gallons daily), before dilution with subsoil water, which raised the average outflow to 975,000 gallons in dry weather, was perhaps as filthy as that of any town in England; for although out of two thousand seven hundred and twenty-seven houses only four hundred and fifty had water-closets, the overflow from sixteen hundred common privies was discharged into the sewers, in addition to the liquid refuse of several large woollen and carpet manufactories, tanneries, paper mills, and marble works. Why were these facts ignored, and only the water-closets spoken of, which afforded no criterion of the strength? From particulars supplied

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by Mr. Banks[1] on the 17th of December, 1874, it appeared that, although the Author had gone out of his way to show that the quantity of land used for Intermittent Filtration had been understated when declared to be 5 acres, the actual quantity was really only 4 acres 2 roods 25 poles. Mr. Banks added, "We had a good sale of our crop considering what it was. We made £91, equal to about £17 per acre." This return was obtained within a period of six months, under all the disadvantages attending a first crop sown late in the year. It was remarkable that in 1875 the sum of £100 had been obtained from the same 5 acres of land. The arguments founded by the Author on his assumptions became utterly untenable, if the facts were as had been shown, and could be proved at any time. He need hardly add, that as he recommended

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[1] Population of Kendal—13,500.

Water supply—400,000 gallons per twenty-four hours.

Quantity of sewage diluted with subsoil waters, but irrespective of surface waters, delivered to and distributed over the filtration areas daily.

(A) Maximum—1,800,000 gallons per twenty-four hours.
(B) Minimum— 750,000 " "
(C) Average — 975,000 " "

N.B.—The maximum quantity here stated does not represent the maximum of our sewage, but only the greatest quantity delivered on the irrigated land, our outlet sewer below the storm overflow being capable of carrying only 1,800,000 gallons per twenty-four hours. Our maximum flow in winter is upwards of 5,000,000 gallons per diem, ⅞ths of which are subsoil and surface water.

Quantity of land to which these quantities of sewage and subsoil water have been applied.

The total area, including paths and carriers, devoted to the filtration beds is 5¼ acres; but the area to which the sewage is actually applied is 4a. 2r. 25p., divided into four ranges of beds, three only of which, containing 3a. 2r. 0p., being used each twenty-four hours, the sewage running eight hours on to each in succession, and the remaining fourth being used alternately with the others as a reserve, and for change whilst working the crop.

Effluent water from under drains of filtration areas—

(A) *Quantity.*—In ordinary weather, when the river is at a medium level, the outflow from the under drains averages one-third of the quantity of sewage delivered on the land, the remaining two-thirds being lost in the gravel. When the river is very low, the whole of the sewage disappears in the gravel subsoil, and no effluent runs out into the river.

(B) *Quality.*—The effluent water from the areas is perfectly colourless and sweet; in fact, with the exception of a slightly brackish taste, is good, potable water, which I have drunk many a time.

(Signed) JOHN BANKS,
Kendal, Dec. 17, 1874. Borough Surveyor.

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the Corporation of Kendal to prepare 15 acres instead of 5 acres, he was not satisfied with, though astonished, at the results. The charge on the ratepayers, however did not exceed 1½*d.* in the £ for the disposal of the sewage alone.

The evidence afforded at Merthyr Tydvil and at Kendal conclusively proved that where suitable land was properly prepared, and properly used for Intermittent Filtration, it was difficult to make the charge upon the ratepayers of any place where it was adopted exceed 2*d.* in the £. This fact was worth all the special pleading that could be brought to bear upon the subject. A letter received from Baron von Liebig just before his death was so conclusively in favour of Intermittent Filtration, as a means of disposing of trade liquid refuse, that no excuse was needed for giving it verbatim:—

SIR,

Receive my best thanks for your letter of the 3rd instant, and for the paper on "Intermittent Filtration through Natural Soil." I have read this with great pleasure and real satisfaction. You have utilised in the most effective way for the service of populations, the natural law which I laid down in my book, the "Natural Laws of Husbandry," pp. 113 and 114. Your plan for the purification of liquid sewage and the removal of its injurious qualities, as well as the technical execution of the plan, and the use of sewage as manure, are alike excellent, and I only wish that use may be made of it in other places. In Silesia for some years past the best use has been made of your principles, in the Beet-root Sugar Manufactory of Herr von Rath. In the neighbourhood where this manufactory is situated there is a want of spring water and of water generally, and this want has called forth the following arrangement. All water that has been used in the manufactory, and generally all waste or foul liquids, are discharged on to a well-drained piece of land close at hand, and the filtered effluent water is collected in a well. It is pure and clear, and it is again raised by a pump and used in the manufactory as fresh water. Enormous crops of grass are obtained from the piece of land which serves for filtration.

Believe me, yours truly,

J. v. LIEBIG.

In the last section of the Paper the Author asserted, without proof in support of the assertion, that no reasonable apprehension of the silting up of tidal channels need be felt from the outflow of sewage. He begged to state, as the result of many years' observation, that his conclusion was the reverse of that to which the Author had arrived. He was satisfied that the discharge of the sewage of the metropolis with all its solid ingredients into the Thames, at the entrance to the port of London, was at this moment slowly, but not less surely, silting up the river; and though years might elapse before dredging failed to recover a free passage, it was quite certain that the admirable works of Sir Joseph Bazalgette

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for the sewerage of the metropolis would sooner or later suffer detraction on that account.

Dr. FRANKLAND said he should confine himself chiefly to those points of the Paper which dealt with the chemical aspect of the subject. The Paper contained a clear and condensed summary of sewage processes, embracing a wide range, and dealing with a large amount of original investigation. It would be a matter of regret if this really valuable summary were allowed to be in any way marred by inaccuracies that might have crept in during its compilation, and he trusted that he would be pardoned if he frankly pointed out some inaccuracies which, in his opinion, it contained. The chemical processes, hitherto applied to the purification of sewage, were so well known that it was scarcely worth while to discuss them in detail, and he would only remark that they depended essentially upon the production of certain solid compounds within the body of the sewage, which solid compounds carried down with them the suspended matter of the sewage, and a certain small proportion, varying with the quantity of the solid so deposited, of the polluting matters in solution. The principal solid matters thus produced within the body of the sewage were carbonate of lime, alumina, oxide of iron, and carbonate of magnesia. There was also the phosphate of alumina, which, however, did not differ in its character from the other materials. These chemicals were nearly identical with the chief constituents of the earth's surface, and consequently the sewage was practically exposed to a small quantity of earth. This exposure removed a small proportion of the soluble polluting constituents from the sewage. It had, however, been shown over and over again that the soluble constituents of sewage constituted about six-sevenths of the total polluting matter present in the sewage, and the problem was to remove the greater part, if not the whole, of the soluble polluting materials. This artificial production of the most abundant constituents of the earth within the sewage itself gave a correct view of the hopeless competition in which chemical processes were engaged. Of all these processes, perhaps that brought forward by the Native Guano Company had reduced the problem to its simplest proportions. In that process a comparatively large quantity of clay was applied to the sewage. The process consisted essentially of adding alum, blood, and clay to the sewage. The blood might, he thought, be regarded as the non-essential ingredient. It was added in such small quantities that it might be termed a colourable pretext. A large quantity of clay being put into the sewage, the inventor afterwards went through the farce of adding

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to it a little more clay produced by the precipitation of alum by the carbonate of ammonia in sewage. The precipitate was alumina, which was substantially the same material as clay. This method, which was, he believed, thought by some to have been suggested by Moses, certainly went just in the opposite direction to that which Moses recommended. Moses recommended that the sewage should go to the earth or soil, not that the soil should be brought to the sewage. These chemical processes had been a failure, so far as the extraction of the soluble polluting materials were concerned, and also so far as the production of a marketable manure was concerned. There was, however, one method, that proposed by General Scott, which certainly did not fall foul of the latter stricture. General Scott did not propose to obtain a saleable manure, but a valuable cement. The quality of the cement so made was rather a question for engineers than chemists, but General Scott frankly stated that he did not profess to remove such a proportion of the soluble constituents of the sewage as to render the sewage inoffensive. The various inventors and experimenters were, however, deserving of much more credit than the Author had given them, when he wrote, "The Sewage Question has not made much progress, so far as discovery and invention are concerned, during the last quarter of a century, nor does there seem to be much prospect of any new or startling light being thrown upon it in the future" (*ante*, p. 105). That was rather hard, and a little ungenerous towards those who had earnestly devoted their attention to the purification of sewage by chemical processes. Although there was a tendency to slight negative results in science, which showed how a thing could not be done, such results were really a substantial advance in knowledge. They arrested attention from that particular mode of dealing with the subject, and concentrated the energies of future investigators upon other methods. The men who had worked out these chemical processes had done even more than this, for, taking their efforts in connection with what had been done in other directions, they had finally reduced the sewage question to one of extreme simplicity. The simple question now was, Shall the soil be brought to the sewage, or shall the sewage be taken to the soil? This was obviously a question for engineers, and he left it with perfect confidence in their hands.

The Author next proceeded to consider the application of sewage to land. In treating this part of the subject he would assume that the answer to the question he had just stated would be, Take the sewage to the land. If this were so, there were

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still two modes of dealing with it when it was taken there—first, Irrigation; and, secondly, Intermittent Filtration. The chemical action of both these processes had been clearly demonstrated to be one and the same. They were the real chemical processes. The other so-called chemical processes were only indirectly so; they merely produced, by chemical means, a certain solid matter in the sewage, which afterwards acted mechanically upon that sewage. Irrigation and intermittent filtration acted in two ways upon sewage. They first removed the soluble filth by surface attraction. This also was the action of the precipitated materials within the sewage, though the quantity thus brought into contact with the sewage was so small that only a small proportion of the soluble polluting constituents could be thereby removed; but in irrigation and intermittent filtration, when properly conducted, there was a true chemical process supervening upon the mechanical one of surface attraction. The second process was the oxidation and destruction of the filth removed by surface attraction, by the absorption of atmospheric air into the pores of the soil, and the transformation of the polluting matter into non-polluting, but still fertilising ingredients. Upon these ingredients so produced, and probably on these alone, the vegetables grown upon irrigated fields flourished. They were incapable of assimilating, at all events more than a trace of, organic matter: they required the organic matter to be first transformed into mineral or inorganic matter before they could make use of it. The Author had pointed out that, in the effluent water at the Barking farm, no less than 70 per cent. of the total fertilising constituents present in the sewage ran away. Mr. Bazalgette was quite justified in drawing that conclusion from the analyses he had before him. It was, however, rather an extreme case. If the corresponding results obtained from other irrigation farms were taken into consideration, the conclusion would, he thought, be arrived at, that probably about one-third was the average of the fertilising material which was wasted in the effluent. But then the Author went on to contend, that probably the greater part of the remainder, after 70 per cent. of the Barking soil had been wasted, was lost by evaporation into the atmosphere. Carbonate of ammonia, it was true, was very volatile, and it was quite within the bounds of possibility that it might volatilise and be dissipated in the air; but as a matter of fact, the carbonate of ammonia did not volatilise under these circumstances. If Mr. Bazalgette referred to page 93 of the First Report of the Rivers Commission, 1868, he would find there a number of experiments showing that solution of carbonate of

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ammonia of about the same strength as sewage, exposed for days even to a rapid current of air, lost apparently but a small quantity of the carbonate of ammonia; and he believed every chemist would allow, that the solution of carbonate of ammonia absorbed in the soil would lose nothing. The soil had the property of imprisoning within its pores large quantities of carbonate of ammonia. Guided by this supposition, the Author was led to believe that pure water—using the word in the ordinary sense of unpolluted water—would answer quite as well for irrigation as sewage. Chemistry at once gave a negative answer to such a supposition. The water did not contain the ingredients which could produce the crops derived from soils irrigated with sewage, and he had little doubt that agriculturists would say that no such crops as those grown by Mr. Hope at Romford, or on the Barking farm and other sewage farms, could be obtained by mere irrigation with ordinary river water. He thought it would be found, on investigation, that in those cases where there had been really good results by irrigation with ordinary water, the water contained a large proportion of nitrates in solution. He knew this to be the case in many irrigation fields in the Gloucester valley; while waters from mountain sources, which were quite devoid of these nitrates, produced little or no effect, except in dry seasons, when of course the application of water to land was always attended with advantage. As regarded the quantity of sewage necessary to fertilise an acre of land, he would merely make a remark in passing. So far as his experience had gone, he had come to the conclusion that about 50 persons per acre were quite sufficient. He was quite willing to admit that this number might vary somewhat in different localities, different soils, and different climates; but he was speaking of the English climate. The Author stated that at Bury this quantity was enormously exceeded, namely, to the extent of 577 persons per acre; and in connection with that, he remarked that there was absolutely no effluent. Probably he only meant that there was no apparent effluent, because it was inconceivable that all the liquid could evaporate from the sewage. The soil was an exceedingly porous bank of gravel, which rapidly absorbed the material thrown upon it, and no doubt purified it very completely.

He now came to the second process, by which the sewage could be treated when brought to the land, namely, Intermittent Filtration, or Intermittent Downward Filtration, as it was sometimes termed. This process the Author spoke of rather contemptuously, and laboured hard to prove, first, that it was not

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new; secondly, that it was not true; thirdly, that it never had, and never could have, any existence; and then, somewhat inconsequently, concluded by recommending its adoption. It was not for him to attempt to prove that the application of the sewage of even 1,000 persons—not to speak of 3,000—to the acre was a discovery. It certainly lacked the stamp of a patent, and the promotion of a limited liability company; but the Author seemed to entertain some singular ideas with regard to what constituted a discovery. He seemed to intimate that to imitate nature—to control, modify, and intensify natural operations—was not to invent or discover. Most people, however, would admit that the man who first artificially made common alum in imitation of the Roman alum, which was naturally made in a volcanic district, was a real inventor, or something nearly approaching to it; and although the process of Mr. Gossage of Widnes, by which common salt was decomposed in the presence of steam at a high temperature, was really an imitation of a natural operation, a patent had been granted for it, and he had never yet heard the invention questioned. There were hundreds of illustrations of the same kind, but he would only allude to one more, namely, the imitation of the natural operation of producing paraffin and paraffin oil, discovered by Reichenbach and Young. Both those men were really discoverers, in placing within the reach of man methods for producing such useful materials by a process independent of natural operations. This, however, was a point he did not intend to discuss. All he would say was that the idea was new to him. The question now was, Would Intermittent Filtration perform the purification that had been asserted of it? He would first of all allude briefly to the laboratory experiments which had been criticised. Two preliminary experiments were made in glass tubes 16 feet long and 2 inches in diameter. These showed, as the result of numerous analyses, that 5·6 gallons of London sewage could be perfectly purified by a cubic yard of the sand which was put into the tubes—a mixture of sand and chalk in one, and pure quartz sand in the other—and that 11·2 gallons were rather imperfectly purified. Those were experiments on too small a scale, and ought to be put aside, although the results were by no means unsatisfactory. The other experiments were made in glass cylinders prepared for the purpose, 6 feet long and 1 foot in diameter. These were filled with porous soils, and one with peat. The experiment with peat was, of course, made solely in the interest of science, not with any expectation that it would succeed. Peat was not a material that any one

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would select as a filtering material for sewage; but as there was a great deal of peat in the country, it was important to ascertain whether it would do anything in this direction, and it purified 4 gallons of sewage per cubic yard, and promised to do more in future, for it began badly, and went on better and better to the end of the experiment. He did not, however, regard that as a fair specimen of what could be done by intermittent filtration, and therefore that cylinder ought to be disregarded in ascertaining what could be done in laboratory experiments by intermittent filtration. The same was the case with the second cylinder, which contained soil from the Barking farm. That soil was of such a character that when put into the cylinder it became almost impervious to sewage. From its being of a somewhat gelatinous consistency, it afforded but a slow passage for the sewage, and really did not purify at all. It was an utter and complete failure, and was described as such in the Report of the Rivers Commission. There were then three kinds of soil left. That brought from Dursley in Gloucestershire purified most satisfactorily 9·9 gallons of sewage per cubic yard of soil, and purified almost satisfactorily 12·4 gallons. The Author had taken no note of the 12·4 gallons, and objected that the Rivers Commissioners took 10 as the purifying power of that soil instead of 9·9. It was only fair to the Dursley soil to take the mean of these two results, because the standards of the Rivers Pollution Commissioners were only infringed at the higher rate to a slight extent during three months. He therefore proposed to take the mean of these two, namely, 11·1 gallons. This gave 3,737 persons to an acre of land when the drainage was 6 feet deep. The Beddington soil purified with the greatest readiness 7·6 gallons of sewage per cubic yard of soil. It also purified 15·2 gallons, a quantity which was gradually reduced to 7·6, but so long as it was continued 15·2 gallons were thoroughly and completely purified, although there were indications that it could not keep up this high rate. The Author, however, never mentioned the 15·2. Here again it was only fair to take the mean of the two numbers, and that would give 11·4 gallons per cubic yard. This was equivalent to 3,838 persons per acre of land drained 6 feet deep. The Hambrook soil, which was inferior to the others, purified most efficiently 6·2 gallons per cubic yard in twenty-four hours, equivalent to 2,087 persons per acre. Taking the mean of these results, 9·6 gallons of sewage were purified in twenty-four hours by a cubic yard of soil, or the sewage of 3,220 per acre. At 15·2 gallons the purification effected by the Beddington soil was three times as good as it need be; the

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effluent water was three times as good as that prescribed by the standards of the Rivers Commission. The effluent from the Dursley soil at 9·9 gallons was twice as good; and at 12·4 gallons it was but slightly above the standard. The effluent from the Hambrook soil might have been 40 per cent. worse, and still not have infringed the standards. The maximum of what was done in the laboratory, as given by the Rivers Pollution Commissioners, was the purification of the sewage of 3,330 persons per acre, while the maximum of these experiments was 3,838 persons per acre.

He would next turn to the practical results at Merthyr Tydvil. The Author had stated that the Rivers Pollution Commissioners in their Report had placed it on record that the sewage of 50,000 people was cleansed on the filter beds at Merthyr Tydvil upon 20 acres of soil. He said, "It stands upon record that at Merthyr the sewage of a population of 50,000 has been satisfactorily purified upon 20 acres of land, or in the proportion of 2,500 persons to an acre" (*ante*, p. 131). That record existed entirely in Mr. Bazalgette's imagination. There was no such statement in the Report, and on the very page from which the Author had quoted there was the following sentence:—"20 acres of a porous soil, drained from 5 feet to 7 feet deep, have been arranged by Mr. J. Bailey Denton, C.E., in four series of beds, and over each series in succession the drainage water from a town of 50,000 inhabitants, more than one-third of whom are connected with the sewers, is poured for six hours at a time;" the evidence given before them having been that out of ten thousand houses three thousand five hundred were connected with the sewers. Mr. Harpur, the engineer, gave evidence that the discharge down the grids, and the overflow of cesspools, would amount to one-third more. Had the Author given a fair quotation of what was really intended in the Report, much invective against the Rivers Pollution Commissioners might have been saved, for he had gratuitously put into the mouths of the Commissioners a statement which he afterwards proceeded at leisure, and with some amount of zest, to demolish. What did the Merthyr filter beds really teach? In the first place, they taught that the application of the sewage of more than 1,000 persons per acre was consistent with the cultivation of crops upon land, and with superabundant purification of the effluent water; and, secondly, that the sewage of a much larger number of persons could be effectually purified upon an acre of land, if the growth of crops were given up. The Author had tried to make out that there was a strain upon these filters when the sewage of 1,200

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persons per acre was being drained upon them. How far that was the case might be judged from the results of the analyses of the effluent water, extending over four years. He could only state generally that the effluent water analysed on the 19th of June, 1871, when the 1,200 people per acre were put upon the 20 acres, was seven times as pure as it needed to be; and on the 21st of October, 1871, when the number put upon the 20 acres had been reduced to 500 people per acre, the purification was fifteen times as good as it need have been. There was a discrepancy between this statement and the Author's. The Author quoted quite correctly from the Report, but if he had been on the *qui vive* for facts against his attack, he would have seen that those figures were corrected in a subsequent Report in 1874. The numbers that he did give showed a purification five times as great as necessary, but the other analyses given side by side with it showed almost on the face of them that that must be an error. These two analyses were of samples taken at the beginning and the end of the operation, and the numbers quoted by the Author were the results of an analysis of an average sample taken during the whole time. The average was twice as much as the means, and that being improbable, the Author ought to have investigated the matter a little further. The real numbers obtained on analysis showed a purification fifteen times in excess of that which was needed. In July 1872 the purification was eleven times greater than necessary; on the 17th of October, 1872, it was thirteen times greater; and on the 13th of February, 1875, it was actually thirty times greater, the people per acre having then been reduced to 250. At this latter date the effluent was actually purer than the subsoil water, and he therefore did not make the reduction which he otherwise might have done for the dilution of the subsoil water. The subsoil water was never practically any better than the effluent water, and when only 250 people were discharging their sewage per acre, it was actually much worse. If, then, the effluent was fifteen times purer than necessary with 500 people to the acre, and seven times purer with more than 1,000 people to the acre, would it be a monstrous assumption if it were to be supposed that with 2,000 people to the acre it would be three and a half times purer than necessary, and with 4,000 people to the acre one and three-quarter times purer than necessary? He did not make the assumption; he merely asked the question. One point was insisted upon rather strongly in the Paper with regard to the advantages of Merthyr as a place to carry out this process of intermittent filtration. It was said that the subsoil water there was ad-

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vantageous in diluting the sewage. If the purification were imperfect, no doubt it would be; but in reality he believed the subsoil water was rather a disadvantage than otherwise, because it contained a considerable quantity of carbonate of iron. It was a reducing water, just reversing the action of the filter, which was essentially an oxidising one; and so far as it operated at all, it rather interfered with the efficiency of the filters. The Author had tried to make out that the sewage of 500 persons per acre on the Merthyr beds was the limit of safety; and he adduced the evidence of the Resident Engineer, Mr. Harpur, in support; but Mr. Harpur, when he gave his evidence, was looking to the crop, and not to the effluent water. He was considering what would be the utmost amount of sewage that could be applied with safety to the crops, and he thought the sewage of more than 500 people to the acre would not be desirable. In his evidence, in October 1872, before the Rivers Pollution Commission (Fifth Report, vol. ii. Evidence, p. 163) he was asked:—"*Q.* What do you suppose to be the population draining out of your exit—what number of people?—*A.* The number of people directly connected with the sewers is about 20,000, but they are increasing now, and we are just extending the drains. *Q.* As regards the drainage from the other 30,000 or 40,000, what proportion of their drainage, under this unconnected system of sewerage, also finds its way into the exit?—*A.* As far as the bulk or quantity of drainage goes, I believe it will be found, when the drains are connected, that the increase will be comparatively slight. . . . . *Q.* What proportion of the personal waste of this unconnected population at present finds its way into the sewers do you suppose; I mean of the excrementitious matters?—*A.* I dare say a third of the excrementitious matters of the population not connected directly with the drains, gets into the sewers. . . . . *Q.* The excrementitious matter from 30,000 people?—*A.* Yes. *Q.* Do you agree with Mr. Bailey Denton in supposing that the filtration works below Troed-y-rhiew are incapable of dealing with more than one third of additional inhabitants? —*A.* I do not agree with that. I do not think that Mr. Bailey Denton puts it as a matter of course, but he merely gives that to keep himself within safe limits. *Q.* How much additional waste do you think the whole of that land is capable of defecating?—*A.* I do not think we can suppose that the 20 acres and the 50 acres are capable of taking more than they are taking now. I think that they are sufficiently sewaged. *Q.* You mean sufficiently in the interest of the crops upon them? *A.* Yes. . . . . *Q.* Did you notice when the whole of the sewage was being passed on to the 20 acres, any tendency for

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the land to choke up?—*A.* No. . . . . *Q.* Such filters had not in fact been previously constructed?—*A.* Not anywhere; the idea was perfectly new. *Q.* You have said that you thought the 20 acres would not cleanse much more than the quantity you put upon it as a maximum; on what grounds do you say that?—*A.* I say that under the present arrangement it might be so, because if we put much more on than we are now using, we should damage the vegetation instead of improving it. *Q.* But suppose you decided upon sacrificing the vegetation what would your opinion then be?—*A.* Then I think that we might cleanse the whole of the sewage of the town. *Q.* I think you have stated that you had not noticed any sign of the land being overdosed?—*A.* No, not so far as the cleansing is concerned. I have had trial holes dug practically to ascertain if there were any traces of sewage getting into the land without injuring the soil, but we cannot find any such traces. *Q.* Do you find anywhere at a considerable distance from the surface any tendency to turn black?—*A.* None."

The fact of the matter was, that, in testing the practice of intermittent filtration, the Merthyr filters had been sacrificed to crops. Intermittent filtration had not been tested to its maximum there. It was like employing a 50-HP. steam engine to do the work of ten or twenty horses; nor could it be wondered at that that should have been the case, for Mr. Harpur mentioned, in answer to Question 5861, that the crops of these 20 acres were worth between £800 and £900 per annum. The Local Board of Merthyr would not be justified in sacrificing the money of the ratepayers merely to decide this question for other communities. These filters, then, had actually produced crops worth more than £40 an acre, and they were capable of purifying a much larger amount of sewage than had ever been applied to them.

The scheme proposed by Mr. Hawksley and Mr. Hope for dealing with the sewage of Birmingham was, in his opinion, as near perfection as possible. He believed that local boards and corporations would never be successful farmers. Until the farmer took the sewage, either gratis or at a low rate, no profit would ever be made out of the sewage; and it ought to be a distinctive feature of every sewage scheme, that provision was made along the conduit for the supply of the sewage to the farmers when they eventually opened their eyes to the value of this fertilizing material. That was the scheme proposed for Birmingham, and it was supplemented by intermittent filtration, which would have dealt with the sewage when the farmer did not care to take it. There ought always to be an arrangement that the sewage should not be forced upon the farmer,

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but could be purified by intermittent filtration, the farmer having it when he wanted it.

As to seaboard towns, he in a great measure concurred in what the Author had said. No extensive outfall works were necessary for the disposal of the sewage of such towns; but he would urge upon engineers not to take the sewage of inland towns to the sea. Posterity would never thank them for work of that kind, ignoring the means which science had placed at their disposal for the treatment of sewage inland, and utterly throwing away its valuable fertilising ingredients. If such a course were adopted, he believed the verdict of posterity would be wholly against it.

Mr. SILLAR said it was the fashion, when any particular process was advocated on the subject of sewage treatment, to commence its advocacy by a wholesale denunciation of all other ideas or processes that could interfere with it. This had the effect of diverting the mind from the real points of the case. He was sorry that the remarks had not been confined to an absolute condemnation of the processes in question. With some of those remarks he felt personally aggrieved. Scientific men had investigated closely the action of the blood in the process he had advocated, and when gentlemen volunteered to say that he or any other person had brought it forward as a colourable pretext, it was beyond the province of legitimate debate. The Paper professed to be an advocacy of the plan of throwing sewage into the sea. He considered that was a great waste, and would only be justified if it were really true that there was no better way of disposing of it. He did not intend to say a word against the processes of intermittent downward filtration or irrigation. Certainly the land was the proper recipient for those matters which were polluting elements in the water and fertilising elements in the land, and wherever the land could be had in sufficient quantity and quality, the process of intermittent downward filtration would do the work, or the water might be taken to the land. But there were many occasions where that was not the case. There was a broad distinction between utilising sewage for fertilising land, and utilising a portion, and that perhaps a very small portion, of land for disposing of the sewage. The Paper first of all sought to sweep away the whole idea of precipitation processes, in favour of which he desired to say a word. Dr. Frankland had stated that the irrigation of sewage was a chemical question, and no one would disagree with him. The dissolved impurities of sewage were not to be removed by mechanical filtration, but by filtration through land: therefore it was evident that the earth itself acted as a

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chemical agent in absorbing those dissolved impurities. Was it unreasonable to suppose that if, instead of taking the sewage to the earth, the earth were taken to the sewage and mixed with it until it became turbid, and then precipitated, it would exercise the same chemical action, and that when it was precipitated by alum or other substances, it would take down some of those impurities? He knew by practice that it did so, and why scientific men insisted that it did not passed his comprehension. He had steadily observed the action of the three elements used for purifying sewage, charcoal, earth, and blood. He had never heard any one deny that each had a great power of purification. With regard to the water which came from it, if it were no better than raw sewage, if the deposit was of no value whatever, one might safely talk of throwing it away; but he absolutely denied the proposition. Chemists of equal eminence with Dr. Frankland had asserted that the water was greatly purified. He did not use the word in its strict sense, as meaning without any impurity, but it was so greatly purified as to be admissible into running water. At Leeds, after purifying the water in that way for three years, one gentleman was so impressed with the idea that had been propounded—that the water was little better than raw sewage—that he had asked for and obtained permission to try an experiment. The sewage was put through a tank untreated, and the result was that in a week's trial the best man was lost, having died at the tank side. He had placed upon the table a bottle of water purified at Aylesbury, containing fish still as lively as ever, that had been taken out of the sewage tank, and had remained in the sewage water for two months. If it were said that such fish could live in sewage, he had something to learn on the subject. With regard to the deposit, the earth and charcoal plus the water as taken out of the sewage, put upon the ground and properly dried, came out in the condition shown in the specimen. It had been dried by simple exposure to the atmosphere, and not in any artificial way. If it was only inert matter, simple earth, what possible harm could it do if it were put down even to such an extent as to raise the level of the island? It would be only adding so much more garden mould to it. He maintained that it had a high fertilising power. It had been given to scientific men, and to practical farmers. He had sold upwards of 4,000 tons of it, and three volumes of certificates had been published upon its manurial value. There was a wide difference between manurial value and chemical valuation. He protested against the term "chemical value." The product to which he had referred had

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been put into the hands of an eminent scientific man, Prof. Crookes, who stated, in a letter dated December 1872, "Before I consented to become scientific adviser to the Native Guano Company, I stipulated that I should satisfy myself as to the alleged agricultural value of the manure, by personal inquiry amongst the farmers who had tried it. I devoted some time to this inquiry. With scarcely an exception, the farmers (of whom I saw twenty or thirty) were unanimous in their approval of 'native guano'; many of them shrewd, intelligent men, well acquainted with the various artificial manures in the market; they had tried 'native guano' with intelligence in different fields against other manures, and I was assured that—putting equal values per acre—it was superior to most manures in the market. Moreover, an examination of the books of the Company showed me that the good opinions of the agriculturists were genuine, inasmuch as a man who, the first year, would grudgingly take one ton as an experiment, the next year took 10 tons, and the third year would increase his order to 20, 50, and even 100 tons, grumbling that the limited supply prevented him having all he wanted. The two or three cases in which the opinions as to the manurial value of 'native guano' were adverse I fully inquired into; they were easily explained by local circumstances, excessive drought, or unskilful employment. I discovered nothing which could be fairly placed in opposition to the good accounts I had received in other quarters, and I returned from my tour with the conviction that Chemistry was exceeding her legitimate inferences when she assigned inferior manurial value to the 'native guano' upon a mere estimation of its contained nitrogen and phosphorus." He protested, in the name of science and common sense, against chemical valuations being made to supersede certificates from the highest authorities. After all, the highest authority was the earth itself. The manure to which he had alluded was made at Crossness, under the supervision of the Metropolitan Board of Works; it was jealously guarded, and put into a warehouse under a Chubb's lock, and permission was even refused to put a little salt into the ground to kill the wire-worm. The result, however, was that 10 cwt. to an acre doubled the crop upon the sourest land in the country; but the Metropolitan Board of Works had been silent upon the point. Certificates had been received as to the value of the manure from the head gardener of the Botanic Gardens, Regent's Park, and also from one of the largest landed proprietors in Berwickshire. With regard to Mr. Bishop's field at Leamington, twenty-four members of the Metropolitan Board of Works had gone

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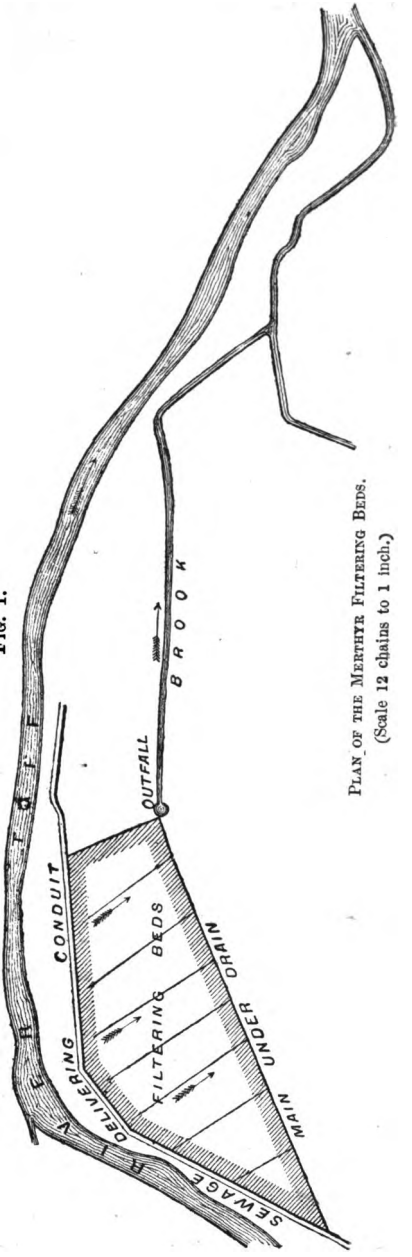
to see it. Sir John Thwaites, the Chairman, looked at the grass and said, "We know that sewage always produces very coarse grass," but the grass in question was really as fine as any he had ever seen. It was distinctly certified that upon ½ acre manured with that material there was a larger crop than on the other 4½ acres in the field. If these things were true, he maintained that throwing sewage into the sea was a most wasteful proceeding.

Mr. Henry Law exhibited a plan (Fig. 1) showing the system of Intermittent Downward Filtration as applied at Merthyr, as there were some special circumstances attending its use at that place. The river Taff did not occupy the lowest part of the valley, which was drained by a brook discharging into the Taff about 1 mile lower down, the bed of the river being precipitous. The filter beds occupied a space falling from the river towards the brook, and the lower part of the beds consisted of a coarse substratum of gravel, so that the waters of the Taff were continually running beneath the filter beds into the brook. It was therefore impossible to draw any general conclusion from a comparison between the analysis of the sewage discharged upon the

Fig. 1.



Plan of the Merthyr Filtering Beds.
(Scale 12 chains to 1 inch.)

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upper part of the filter bed and that of the water which flowed through the brook, and which was commingled with an enormous amount of subsoil water. That alone was sufficient to discredit the results of the analyses. There was another point also to be taken into consideration, namely, the extreme weakness of the sewage. The quantity of solid matter in suspension was only $\frac{2}{3}$ of the average of the sixteen water-closet towns referred to at p. 29 of the first report of the Rivers Pollution Commission. The organic carbon was only $\frac{1}{4}$, organic nitrogen $\frac{2}{3}$, ammonia $\frac{1}{3}$, mineral matter in suspension $\frac{1}{3}$; consequently, any result drawn from the experience at Merthyr would have to be discounted in those proportions, when applied to the average sewage of the country. It had been said that the result had been obtained from an experience extending over a lengthened period. But the real facts were stated by Mr. Arnold Taylor, in a report to the Local Government Board, on the 8th of November, 1872 (*ante*, p. 135). However, on the occasion on which it was proposed by Mr. Bailey Denton to apply the sewage of 24,000 persons on 8 acres of land in the neighbourhood of Barnes, Mr. Harpur gave evidence at the inquiry held before Major Tulloch, to the effect that it was only for five months that the whole of the sewage of 25,000 persons was put upon the 20 acres at Merthyr Tydvil (*ante*, p. 134). That was the evidence of the gentleman who had been in charge of the filtration beds from the time when they were constructed to the present moment. Mr. Bailey Denton had, however, referred to certain analyses by Dr. Frankland, Dr. Russell, and others, as though they had been made after the experience of a year or two, during which these beds had been used as downward intermittent filtration beds, receiving the whole of the sewage; but they had ceased to be so used before any of the analyses had been made. There was no experience to show what the permanence of their action might be. And when it was considered that, in the case of Merthyr, 21 grains in every gallon of the solid matter in the sewage was retained by the land, and that it amounted to 32 cwt. per day upon the 20 acres, how was it possible to conceive that that substance could be left in the soil without the pores of the soil being gradually filled with it? With regard to profit, Mr. Bailey Denton had stated that during the first year, in which he maintained that the system of downward intermittent filtration was still in vogue, a profit of £20 per acre had been made,—to quote his own words, "a return more than sufficient to cover the cost of the 75 acres of land and the whole of the works connected with the 75 acres" (*ante*, p. 185). He thought that upon this point Mr. Harpur's evidence at the Barnes sewage inquiry, before referred to,

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was better than that of Mr. Bailey Denton; he had been asked:—"*Q.* Now, I would ask you, in regard to the profit—have you made any profit from the cultivation of land there?—*A.* I am sorry to say that we have not derived any profit. *Q.* You have not?—*A.* We have not; on the contrary, we have sustained a considerable loss. *Q.* Which is more likely to realise a profit, the irrigation farm combined with intermittent filtration, or the irrigation farm alone?—*A.* The irrigation farm combined with intermittent filtration. *Q.* Will you give us the particulars of your experience at Merthyr?—*A.* In 1872 there was a loss of £624 16*s.* 11*d.*; in 1873, when the area was extended, there was a loss of £598 9*s.*" Mr. Bailey Denton had stated that the smaller the area the larger the profit; but in the case put by Mr. Harpur the loss was reduced as the area was extended. Mr. Denton also observed that, under favourable circumstances, the view of Dr. Frankland, that 1 acre of suitable soil would cleanse the sewage of 3,300 persons could be verified. That of course was a matter of opinion, and Dr. Frankland had made a rather extraordinary statement, taking it from a chemist's point of view, that because the sewage in October 1871 was purified fifteen times more than was necessary for the standard fixed, therefore four times the quantity of sewage might safely be poured upon the land, and yet it would remain upwards of three times more pure than was necessary. If he had been mixing two substances together as chemical reagents, that mode of reasoning might have been applicable; but he forgot that if he put four times the quantity of sewage on the land, it occupied four times as long in running away. Therefore there was only one-fourth of the time remaining to purify it. The amount of work to be done was fourfold in one quarter of the time, which would be equal to one-sixteenth only of the effect. And the result of the experiment quoted by Dr. Frankland, at p. 65 of the First Report of the Rivers Pollution Commission, showed that that was so; because, in his own experiment upon the Beddington soil, he found that with 7·6 gallons per cubic yard the quantity of organic nitrogen in the effluent was 0·07, or four times as pure as was necessary; according to his own reasoning, therefore, double that quantity of sewage might have been put on, and yet the effluent would remain twice as pure as was necessary. He stated, however: "These results show how rapidly the process of nitrification (the conversion of ammonia and animal organic matter into nitrates) takes place in the Beddington soil, and how satisfactorily the sewage is purified even at the rate of 7·6 gallons per cubic yard of soil per diem. But when this rate was doubled the nitrification ceased, and the pores of the

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soil became blocked up so that they would no longer transmit the whole volume of sewage supplied and also afford time for aeration." It was impossible to reason that because the effluent water had fifteen times the amount of purity necessary, therefore four times the quantity of sewage might be put on, and yet the effluent would remain sufficiently pure; for it could not be passed through the soil in the time. Laboratory experiments were of immense value as suggesting processes, but they were worse than useless if the numerical results obtained were to be applied in that way in practice. The soil was taken and carefully sifted, the large stones being removed, and it was well known that the mechanical structure of the soil was really that which enabled it to act in the intermittent downward filtration process. It was put in under the most favourable circumstances. The sewage, having been obtained and brought to the spot, was deprived of the larger and coarser matter which would interfere with the process of filtration; the temperature was always the same, and there was no exposure to the vicissitudes of weather. To draw, therefore, numerical results from laboratory experiments, and to apply them to practice, would lead to serious error. It was also necessary to correct another erroneous statement made by Dr. Frankland, namely, that Mr. Harpur, in limiting the number of persons to 600 per acre, had regard to the profitable cultivation of the land, and not to the power of the soil to purify the sewage. On this subject he would again refer to the evidence of Mr. Harpur, to the effect that, as the result of two years' experience, he did not think it would be safe to put the sewage of more than 500 persons on 1 acre (*ante*, p. 135).

In conclusion, it ought not to be supposed that intermittent downward filtration got rid of the most difficult portions of sewage, namely, the sludge. If the sewage were put on the land without removing the sludge, it would become an intolerable nuisance. The evidence of Dr. Dyke, the medical officer at Merthyr, should be remembered. He had said that where there were two straining tanks, and where so much attention was paid to the extraction of the sludge, 15 tons were taken out every week. Even there, however, a nuisance arose, and the sludge deposited upon the beds had to be dug in. It had been proposed to get rid of the sludge by General Scott's process, but in the ordinary manufacture of cement from the comparatively pure materials of chalk and clay, the nuisance was very great, and injunctions had been obtained against the cement works. He was therefore confident that when the process of making cement from manure was carried on upon

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a large scale, where, superadded to the chalk and clay, there were large quantities of organic matter, the nuisance would become still greater.

Mr. ROGERS FIELD said many statements had been made with reference to Intermittent Downward Filtration at Merthyr Tydvil and at Kendal which were not correct. He had assisted Mr. Bailey Denton in the preparation of the details of the works at those places, had since visited both, and had made a special independent investigation. He had also referred to Mr. Bailey Denton's original documents, and had gone through the whole of the correspondence with the clerk of the works on the ground. The works executed by Mr. Harpur were commenced in the beginning of 1871. In March of that year Mr. Denton was sent down by the Lords Justices, and he reported that the works were altogether inefficient, and ought to be done over again. The Lords Justices then ordered him to take the work into his own hands, and have it completed to his satisfaction. This he accordingly did. Mr. Harpur's statements were correct as far as they went, but they referred to the works which he had done, and which were finished in March. Mr. Denton's works were not finished till October 1871, having been begun at the end of April. In June the Rivers Pollution Commission went down for the first time, when none of the beds now existing, as made by Mr. Denton, had been formed. Sewage was being applied irregularly, as best it could, to improperly formed land; so that the effluent water analysed by the Rivers Pollution Commission at that time could not strictly be said to be that of intermittent downward filtration. On the 5th of August the whole of the sewage was turned on to two new filtration areas, comprising 10 acres, and from that time till the 13th of September it continued to run on to those 10 acres. The population contributing to the sewers was stated by Mr. Harpur, in his evidence before the Rivers Pollution Commission, to be 30,000, and in his evidence at the sewage inquiry referred to by the Author to be 25,000. Taking the lowest number, this would be at the rate of 2,500 people per acre. Then three areas, comprising 15 acres in all, were brought into play, and the whole of the sewage was run on to them till the 19th of October, which was at the rate of 1,750 people per acre. On the 19th of October the sewage was turned on to four areas, composing 20 acres in all, and on the 21st, when the Rivers Pollution Commission again visited Merthyr, the sewage was being applied to those 20 acres, or at the rate of 1,250 people per acre. Dr. Frankland therefore had greatly under-

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stated the case. At the time when the purity of the effluent water was seven times greater than it need be, the sewage was only being applied to improperly formed land, and at the time when the purity was fifteen times greater than it need be, the sewage was being applied at the rate of 1,250 persons per acre, instead of 500 persons per acre. It also appeared that it was not the case, as stated by the Author, that the greatest proportion which ever obtained, even temporarily, at Merthyr was from 1,000 to 1,250 per acre. The actual facts were that for upwards of a month the sewage was applied at the rate of 2,500 people per acre; for another month at the rate of 1,750 people per acre, and after that at the rate of 1,250 persons per acre. With regard to Mr. Harpur's evidence before the Rivers Pollution Commission, it would be found that it differed considerably from that quoted by the Author and by Mr. Law. The difference was, no doubt, explicable by the fact that the evidence was given under different circumstances. The Commission asked questions simply with regard to the facts of the case; but at the sewage inquiry to which reference had been made, the answers were given to certain leading questions. He thought that most engineers would prefer to take the evidence given before the Commission, in which, for instance, Mr. Harpur distinctly stated with regard to the cost of the works, that they had been done two or three times over, and that they might be done again for half the money.

He would now turn to Kendal. The population was acknowledged to be 13,700, and the whole of the sewage really drained to the land. A certain number of houses had cesspools or middens, the overflows of which went to the land. There again he preferred to take the results of the investigations of the Rivers Pollution Commissioners, notwithstanding the doubt that had been thrown upon them. Their investigation showed, as was well known, that the analysis of sewage from midden towns differed very little from that of water-closet towns. He believed that practical experience would confirm the view of the Rivers Commissioners. But even taking the other view, nothing like the deduction could be allowed that had been made. It should also not be forgotten that the numerous manufactories in Kendal drained into the sewers, and, under all the circumstances of the case, he thought it was only reasonable to say, that the sewage of the entire population of 13,700 persons went on to the land. With regard to the question of area, it was stated by the Author that the acreage was 5½ acres; but from this had to be deducted river-banks, roads, &c., to which no sewage was applied.

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He had himself fully investigated that matter, had scaled the quantity from the plan, and had also communicated with the Borough Surveyor, and it appeared that the net area to which the sewage was actually applied was only 4 acres 2 roods 25 poles. The actual proportion of population to the acreage was therefore 2,942 per acre. That had now been going on continuously for nearly three years, with the exception of thirty-five days in the year, on which the sewage was applied to other land. There was not time to dig the material into the ground as satisfactorily as it might be done, but that did not affect the effluent. On the occasion of his visit to Kendal, on the 4th of September, 1874, the quantity of sewage flowing on to the filtration areas was at the rate of 2,000,000 gallons per diem, equivalent to a depth of 19 inches for the whole filtration area, and the effluent water flowing from the outlet of the under drains was clear. The average quantity of sewage flowing out of the land was at least 1,000,000 gallons per diem, equivalent to a depth of 9½ inches over the filtration area. So that, after allowing for the thirty-five days in each year when the sewage was applied to other land, the enormous depth of 261 feet per annum was purified by the filtration areas, and had been so purified for the last three years. This fact alone, which was beyond doubt, rendered Kendal one of the most remarkable instances of sewage purification in the country. With regard to the distribution, it could not be accomplished in the ordinary way, and some automatic method was required, so that the sewage might be exactly and proportionately distributed.

Fig. 2 showed the method of distribution by notch plates, as adopted at Merthyr Tydvil and at Kendal. The sewage was conveyed to the land by the main carrier *a*, on which were four notch-plate chambers. The sewage was diverted from the main carrier, through the sluice *b*, into the chamber *c*, from which it escaped by three notch plates, *d*, *e*, and *f*, the sills of which were on the same level. The widths of these notches were proportioned to the area of the filtration beds, on to which the sewage from each notch flowed. In the present instance notch *d* was 8 inches wide, notch *e* was 18½ inches wide, and *f* 18½ inches; the areas were approximately proportioned to the cubical contents, being respectively about 20 poles and ½ acre. It would be noticed that there were carriers on each side of the main, and that the sewage from the notch plate *d* ran under the main carrier through a 9-inch pipe, rising again into the chamber *h*, which delivered into the carrier *i*, from which it flowed on to the land. This was formed into ridges and furrows, as shown on cross section C D, the sewage

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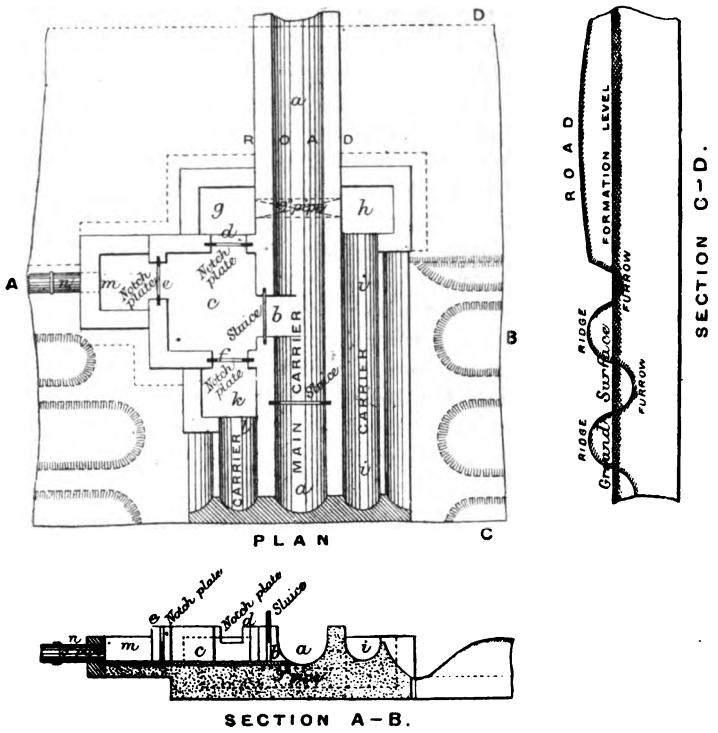
flowing down the furrows, between the ridges which were planted. The notch plate *f* supplied the chamber *k*, which delivered into the carrier *l*, and the notch plate *e* supplied the chamber *m*, which delivered into the 9-inch pipe *n*, conveying the sewage to a third area, not shown in the figure. By this arrangement an

FIG. 2.



automatic distribution of the sewage was effected, inasmuch as, however variable the quantity of sewage flowing out of the main carriers, this quantity would always be apportioned by the notch plates in the precise ratio of the several areas.

From careful observation, he was of opinion that, though it might be possible, with adequate attention, to deal with large quantities of sewage occasionally by the ordinary methods of distribution, no reliance could be placed on such quantities being satisfactorily dealt with for a long time, as variations of flow would frequently occur when no attendant was at hand to alter the stops.

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Some precise automatic system such as that described was therefore necessary. The land, moreover, must be carefully drained, levelled, and formed for filtration areas, which required skilful manipulation. He therefore considered that intermittent filtration differed essentially from irrigation, in that the primary object was not the profitable use of the irrigated land, but the purification of the sewage on the smallest possible area. This was unquestionably an engineering operation, and could only be properly carried out by engineers.

Mr. CHALMERS MORTON would confine his remarks to two points —the performance of the filter beds at Merthyr, and the alleged unprofitableness of sewage farms. On the first, he understood Dr. Frankland to say that he had on several occasions analysed the effluent waters from the filter beds at Merthyr Tydvil, and selecting three occasions when the sewage poured on corresponded to 250, 500, and 1,250 people per acre respectively, he had found, after discounting the dilution from the subsoil water, which, knowing its composition, he was able to do,[1] that the sewage had been cleansed thirty times, fifteen times, and four times respectively more than enough; and he asked, putting his inference in the form of a question, whether, seeing that these filter beds had cleansed the sewage of more than 1,000 people per acre four times more than enough, it was not reasonable to suppose that, if the work had been given them to do, they could have cleansed enough, or even still somewhat more than enough, the sewage of four times as many people? He submitted that that was a reasonable inference; and not only so, but he asserted that this work was given them to do, and that they did it. In justification of that assertion he did not depend upon the important point made by Mr. Rogers Field, who stated that at the time when it was supposed that the whole of the sewage of Merthyr was going on 20 acres, it was only going on 12 acres, thus nearly doubling the work; nor upon another point, of which a good deal might be made, that, although only 4,000 or 5,000 houses in Dowlais and Merthyr were connected with the sewers, so that the sewage of only 2,000 persons was draining on to the filter beds, yet there must have been also a large though indefinite addition of filthy matter from back and side streets, which, though not sewered, found its way through runnels or gutters to the nearest

[1] The subsoil water was in some cases no purer than its effluent, so that it was only in a few instances that there was any deduction to be made from the result on its account.—C. M.

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end of a street that was sewered, and so on to the filter beds. He presumed the Foul Burn below Edinburgh was foul long before water-closets were thought of or sewers made. He would confine himself to Mr. Bazalgette's own admission. When the Author limited the performance of the filter beds to the defecation of the sewage of only 1,000 people per acre, he forgot the important fact that there were large portions of those beds which always had to do four or five times as much work as the rest. If it had been possible so to have distributed the sewage of Merthyr as that every square or cubic yard should receive its aliquot share to deal with daily, then no doubt it would be right to quote their performance as not representing one-third of the duty which Dr. Frankland had declared them capable of of doing. But the sewage was not, and could not be, distributed so evenly. It was not every square yard that received its aliquot part, but every acre. By means of carefully calculated and accurately gauged water-ways, notch-plate chambers, and the like, Mr. Bailey Denton had skilfully contrived that the constant stream of sewage should divide itself into six equal portions, each of which found its way to one-sixth part of the 5 acres under sewage at any one time; and that plot of 120 perches, some 60 by 70 yards in extent, was sewaged from along its edge. But it was not possible to water a sieve, so that every mesh should have its share, by simply putting it slightly a-tilt and watering it from its upper edge. The meshes next the carrier would do all the work, and so it was that the one-fourth or one-fifth part of each plot which was close to the sewer, and which received its full work to do from the beginning to the end of the six-hour period, really did four or five times as much work as the farthest part, which was often not perfectly watered (he spoke as an eye-witness) until two or three hours had elapsed. Therefore he contended that, although the effluent water from the filter beds might be said to be the purified sewage of only 1,000 people per acre, half of it, or more than half, must have come from plots which were dealing with the sewage of 4,000 or 5,000 people per acre. That, he submitted, was a point well deserving of the consideration of any one who came to the study of those filter beds, or even of the blue-books connected with them, not for the purpose of sustaining any foregone conclusion, but of seeking and finding an adequate remedy for the difficulty which all acknowledged, and from which large populations were actually suffering.

As to the second point, the Author was dead against the possibility of profit from sewage farming. Here might be read a letter

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just received from Captain Fosbery, Lord Warwick's agent, who wrote: "You were, I know, anxious to hear the result of our operations on the sewage farm for the last year; I am sure, therefore, you will be glad to learn that we have been successful beyond our expectations. I find that after paying the rent of the farm, and paying the Leamington Corporation for sewage, and interest on the capital invested, there is still a considerable balance left as clear profit. This you will agree is very encouraging, both as regards the undertaking and the possible results of sewage farming generally. I am more and more convinced, however, that to command success, every possible economy must be practised in laying out the irrigation farm in the first instance." He read that letter mainly for the sake of the last sentence, and to urge upon engineers the absolute necessity of their adopting inexpensive methods of distribution if sewage farms were ever to be generally profitable. Looking upon the subject from the agricultural standpoint, he had a farmer's instinctive anxiety and dread with regard to excessive rent. He knew the possibilities of English agriculture, and that an ordinary agricultural rent was borne without difficulty wherever the land was vigorously and productively managed; he knew also enough of sewage farming to be quite certain that even the accommodation rent which corporations and local boards were sure to have to pay was not an intolerable burden where the sewage farm was properly conducted; but when there came in addition to that the enormous rent-charge created by the expenditure of the lawyer and the engineer, the prospect was utterly hopeless. He was perfectly certain that a great deal of the expensive permanent works which he saw upon sewage farms throughout the country was not absolutely necessary. He was recently at Merthyr Tydvil, and found that the account given in the Paper of the present condition of the filter beds was correct; they were dismantled, the whole of the second order of feeders was swept away, and the plough went from one end to the other of the separate filter beds, which were now watered only in their ordinary agricultural turn with the rest of the land. The main feeders were there, and would be for five hundred years to come; but they were not in any degree more useful for their present purpose than so many puddled ditches that might have cost only 7*s.* or 8*s.* per chain. And the land in its present state was just as able to deal with the sewage as it was before. That was put to the test during the present year. In the last week of last year a landslip had carried away a portion of Mr. Harpur's outfall sewer, and the whole sewage of 48,000 people, in a town wholly sewered and water-closeted,

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was for five weeks poured over 50 or 60 or 70 acres at Troed-y-rhiew, and they were found capable of dealing with that unusual burden. He maintained that the excessive cost upon sewage farms generally throughout the country was not necessary. If he were the tenant of 400 acres of suitable land, light and well drained, below a town even with a population of 100,000, and under heavy penalties as to the abatement of nuisance, and the cleansing and defecation of the town drainage, he would say to the engineer, after he had brought the sewage to eight or ten equidistant points upon the land, "I shall be glad of your assistance to distribute it in detail over the several fields, provided you will do it for a sum under £10 an acre. If you cannot do that, I will take my plough and my spade, and my average agricultural labourer, and do it myself." Because he was perfectly certain that any shortcomings in this rough-and-ready work would be covered by the power of porous land to deal with sewage, which was far greater than engineers seemed to believe. There was no necessity for permanent carriers to every 2 or 3 acres of land, nor for subsidence tanks to any great extent. On that point he spoke from experience. When the Metropolitan Sewage Company put into his hands their Lodge farm near Barking to manage, he had come from Rugby, where he had been employed to arbitrate between the commission on which Lord Essex served, and Mr. Walker, the proprietor of the land, on account of an injury done to the permanent grass land by ponding the sewage and covering the land with mud and sludge. At his desire a tank was made with a horizontal rim of 40 yards, into which the sewage was poured, 250 or 300 tons an hour, and from over the lip of which it went on more slowly, leaving the sludge behind it. After the first week he had never used the tank. The sludge was sent on to the land along the carriers, and it did no harm; indeed it did good, because the ditches were cut in gravelly land and it was useful in making them watertight. He did not believe in the necessity of those works of permanence and precision for which Mr. Rogers Field argued, the cost of which was the ruin of the sewage farmer; but what he did believe in confidently was the truth and trustworthiness of Dr. Frankland's discovery, the astonishing power of an aerated porous soil and subsoil to oxidise and defecate town sewage.

Professor ANSTED wished to direct attention to the dry earth system, as it was called. That term he supposed included the pail system, and all the other systems involving the collection of the solid fæcal matter and the waste of towns, and the disposal of it

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without water carriage. Not only the Author, but many others had "pooh-poohed" and contemptuously denied the possibility of this being a practical system, on the ground that, instead of being substitutive for a water carriage system, it was merely supplementary to it. No doubt that was so; but it should be remembered that a large number of towns in the manufacturing districts of England, having already a water-carriage system, did supplement it, to a certain extent, by the dry earth system in one shape or another. He had made out a list of a few towns in which that plan had been adopted, and he named ten manufacturing towns, the population of none of which was under 50,000, and whose total population approached 2,000,000, in which the houses with water-closets was not nearly one-half those supplied by pails, and not one-third of the number supplied at present only by middens. This view of the subject seemed to make it clear, that the mere fact of requiring a water drainage system in addition, was not necessarily destructive of the possibility of using one or other of the dry systems. It was evident that a water-carriage system must be adopted in all cases to carry off the ordinary waste of water supply, and the storm waters that fell upon the surface. But referring to such towns as Blackburn, Birmingham, Leeds, Leicester, Manchester, Nottingham, Oldham, Rochdale, Salford, Sheffield, and many others, where did these waste waters go? Necessarily, and in the case of almost all the large manufacturing towns of England, on each side of the great backbone of the country, near which these towns were situate, the water must be carried into very small streams, and if besides water they contained also the sewage of the vast populations of the towns, those streams would be rendered much worse that they already were. It was, therefore, important that the water-carriage system should in such cases be supplemented by some method which would enable the solid and offensive part of the refuse to be got rid of in some shape or other. The dry earth system, then, ought not to be disposed of by a mere expression of contemptuous impossibility. He had taken considerable interest in this subject from having not long ago seen what was doing in Manchester. In Manchester only about 10,000 houses were furnished with water-closets, while 25,000 houses were supplied with pails. It would not do to speak of a system extensively applied to a city of 360,000 inhabitants as wholly impracticable. The solid part of the refuse was there carried to the town yard, which was quite within the town; and, certainly, as far as he could detect, it was not a nuisance. The quantity of material thus carried was 80,000 tons per annum. Of this quantity 33,000 tons consisted of breeze

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and garbage, offal, and house refuse. About the same quantity of fæcal matter mixed with ashes was obtained from the pails, daily removed from the houses by carts constructed for the purpose, and there were 12,000 tons of liquid matter, chiefly urine, also brought by the pails. The pails were not a nuisance; the refuse as received into the yard was not a nuisance. It was treated in a simple way, and one which appeared to him satisfactory, it being subjected to combustion. The refuse was passed through furnaces of different construction. In one kind it was entirely destroyed; in another there was a certain quantity of organic charcoal obtained from it, which was used, mixed with carbolic acid, to make a fluid to disinfect the pails. The clinkers or solid residuum were ground up, mixed with lime, and made into mortar. The liquid part was treated by an ingenious process, analogous to that employed in sugar-refining, evaporation being caused by passing the material over blades through which a current of extremely hot air (about 600° Fahr.) was passed. The fluid that came out was a small percentage indeed of that which went in, and was available for use as manure when mixed with the refuse of slaughter-houses and deodorised fæcal matter. In that way it was made into solid sewage, capable of being placed in bags and carried off either by boats or by rail. The sewage thus obtained was said to be worth 10*s.* or 12*s.* a ton. In this way all that part of the sewage which was troublesome and liable to be mischievous was got rid of. It was, he thought, important that this method should be carefully examined. It was now in operation on a large scale, and should be recognised as a system which might perhaps afford a key to the disposal of this mischievous mass which was now troubling engineers. It was quite true that it might not be applicable everywhere, but he thought it impossible to devise one scheme for the treatment of sewage under all circumstances. Use must be made of the means at hand. In such a town as Liverpool, where the sewage could be carried to the sea with facility considerably beyond the town, and where there was no chance of its being drifted back, it might be advisable to use the water system entirely. In a city like London it was quite possible that means might be adopted to carry the sewage away to some part of the great tidal river Thames where it would do no mischief, though he confessed, from what he had seen, from the experience of others, and from the evidence which had been given, it would appear that this was by no means effected at present. Perhaps even yet it might prove necessary to burn off the accumulating mass which was being deposited in the neighbourhood of

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the London outfalls. But he thought it should be recognised, at all events, that different towns might require different systems, and that it was not fair to throw aside as valueless a method that had proved to be successful in any one case. On reading the Paper he found five methods mentioned by the Author by which sewage was supposed to be treated, and four of these were, in the conclusions, declared to be utterly unfit and useless in every sense of the word. The only method left was that of seaboard or tidal outfalls; but it was certain that that could only be applied to a few towns round the coast, and could not possibly be applied to the great manufacturing districts of the interior. Under these circumstances he hoped he would be excused for having alluded to one of the despised methods, though it was that one which appeared to be the least respected of all. He considered the Author's remarks on this subject were not by any means fair, for he referred to London as a test place for the application of the dry earth system. London was perhaps the least fitted of all towns for such a system. The larger the town, perhaps the less adapted was it for such a method of disposing of the sewage; but he contended that the estimates of cost given in the Paper, even in respect to London, were totally out of the question. It was by no means necessary that the cost of replacement of dry for water closets should be anything like what had been stated, and certainly such a large quantity of dry earth as was suggested would not be required. If in Manchester ashes could be used to deodorise, why not elsewhere? The Author had come to the conclusion that there was only one system that could possibly be of any use, while he contended that such a method could not be adopted in many places, and did not appear to have been safely adopted in any.

Mr. Adam Scott said, there was not a single point in the Paper with regard to the Liernur system, or in the recent report of the Government Commission on Sewage, that he was not prepared to controvert. The Author had referred to the papers read at the Conference at the Society of Arts last year, and he appeared to have gone through them with the view of taking out anything damaging to the Liernur system. It was incomprehensible, therefore, that he could possibly have overlooked what the system really was, because it was described in those papers. He stated that the Liernur system only dealt with solid and fluid excremental matter, whereas it was a system for dealing with all descriptions of town sewage. He called the Liernur system the pneumatic system, which however was in reality only

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one subdivision of a comprehensive system of town drainage. The pneumatic part of the system, by dealing with excremental matter, separated the most dangerous part of town refuse, which was the cause of typhoid, cholera, and a number of other diseases, removing and collecting the material in such a way that those diseases were impossible. Where sewers were required Captain Liernur provided sewers of an impervious nature, so that the subsoil could not be polluted by sewage of any kind; and where sewers did not exist, a system of drainage by agricultural drain-pipes was given to the subsoil itself. Captain Liernur further insisted upon the purification of manufacturing refuse before it was turned into the sewers. He did not think it desirable that street detritus should go into the sewers and thus complicate the sewage question, and he therefore provided simple upward filtering mud gully buckets, by which the mud would be detained to be removed by scavengers from time to time. It was only dirty street and dirty house water that went into the sewers, and that could be purified, if desired, by means of gas-coke filter beds. There being little solid refuse to deal with, those filter beds were effective in their action. The system did not require huge intercepting drains to carry the sewage to a distance. The treatment was of a simple and innocuous character, and it could be carried out at any part of the river. The operation of the system was being carefully watched by the official Board of Sanitary Officers of Holland, which was composed of twelve government medical inspectors. In the year 1869, at a meeting held with regard to the sewerage of towns, it was resolved by that board that the Liernur system was theoretically the best known, but as they could say nothing about it technically or financially, they reserved their opinion on those points. In the year 1876, however, at their October session, after inspecting the poudrette works at Dordrecht, they unanimously resolved to recommend the universal adoption of the system in Holland. "No other system," they say, "answers so fully or so well for the gathering and removal of excremental matter, slop and rain water, and manufacturing refuse, and for the regulation of the subsoil water, as the Liernur system, as well from a sanitary as an æsthetic, technical, and economical (agricultural and financial) point of view." Either those gentlemen did not know the meaning of the words they used, or others must be mistaken in their views. Mr. Scott hoped that, at all events, judgment would be suspended until the opinion of the other side had been heard. Mr. Bazalgette had said that the pneumatic subdivision of the Liernur system was merely sup-

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plementary, and conferred no corresponding advantage. He must have been ignorant of the striking fact that the pneumatic system had banished typhoid fever and diphtheria wherever it had been put in operation. This surely was a "corresponding advantage," for in this country one person in every two hundred of the population was each year stricken down by typhoid fever alone. The Author stated that the pneumatic system was complicated and liable to get out of order, whereas the Dutch authorities held that it was simple, and where Captain Liernur's plans were followed never got out of order, or gave any trouble. Mr. Bazalgette said that the closet arrangements, which he had not seen, were offensive; whereas at the Society of Arts, in April 1875, Mr. Abbott, of the Tottenham sanitary authority, said that "he had seen some scores of the closets," without water, "in some of the poorest localities in Leyden, Amsterdam, and Dordrecht, and was much surprised to find that they were positively sweet and pleasant; in fact, superior to the average arrangement to be found in middle-class houses in England as regarded freedom from all kinds of effluvium." Dr. Buchanan, Medical Inspector of the Local Government Board of England, at the same meeting, confirmed this, but he had not seen more than thirty closets; and other testimony to the same effect might be quoted. With regard to the decanting arrangements at the central stations at Leyden and Dordrecht, there was no offence, nor would there be any at Amsterdam if the apparatus provided by Captain Liernur was used.

Mr. ABERNETHY, Vice-Presidnet, said the Author had displayed a considerable amount of industry in collating from various sources what might be regarded as the history of sewage disposal up to the present time, without arriving at any definite or satisfactory conclusions. All the information contained in the Paper, and in the more detailed report of Messrs. Rawlinson and Read, led to the inference that no arbitrary rules could be applied with regard to the disposal of sewage; that each case must be treated upon its own merits, and with regard to its local features, such as the amount of population, the nature of the surrounding soil, the possibility of gravitation, and the like. One thing was certain, that the authorities of towns would have to treat the problem irrespective of the question of profit to be derived from the sewage. With regard to irrigation, he thought that in the case of cities or towns of moderate population, where the surrounding soil was of an open, friable loamy or sandy nature, and gravitation possible, that method might be resorted to even with profit. In other localities of a similar nature with regard to population, where the surrounding soil was of a heavy un-

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favourable character, it was obvious that precipitation and deodorisation should be resorted to, passing the effluent waters, purified up to a certain standard, into any neighbouring stream or river. In the case of large cities like London and Glasgow, the problem was more difficult; irrigation was not always available, and precipitation seemed to be out of the question, having regard to the great amount of solid deposit to be dealt with. Probably the only practicable and most economical plan in the case of such cities was to get rid of the sewage by passing it into the sea. But he deprecated half measures, such as the disposal of the sewage of nearly 4,000,000 persons into a river of the volume of the Thames, a few miles beyond London, and in the neighbourhood of a populous suburb like Woolwich. He totally disagreed with the Author that "it would seem to be a logical inference, in the absence of disturbing causes, that where the velocity of the current into which the sewage is discharged is greater than the velocity of the current which carries it down through the sewers to the outfall, there cannot be much danger of silting-up or interference with the navigable channel" (*ante*, p. 157). And he was at issue with him with regard to the effect of the sewage discharged from the metropolitan outfalls. All facts tended to a conclusion entirely at variance with such statements, and having regard to those facts, he maintained that from the metropolitan outfalls a large amount of deposit existed in the bed of the Thames, both below and above the outfalls, but more particularly above. At the present time the river-bed opposite Woolwich had shoaled to such an extent that before long, for purposes of navigation, dredging would, in all probability, have to be resorted to, and if that took place during the summer months it would be very objectionable in a sanitary point of view. He had lately read the able report of Sir John Hawkshaw on the disposal of the sewage of the city of Glasgow, and he cordially recommended the conclusion with regard to the outfall to the notice of Sir Joseph Bazalgette, who had also dealt with the question of the disposal of the sewage of that city. Sir Joseph selected Clochinch, 24 miles below Glasgow, and 5 miles below Greenock, where the river was from 1½ mile to 3 miles wide at its embouchure and estuarian in character. Sir John Hawkshaw did not think that sufficient, and had recommended the outfall to be at a point 15 miles from Clochinch, where it would be subject to a strong tidal current. In cases where irrigation was not available, and the soil unfavourable, deodorisation and precipitation would have to be resorted to, and the inhabitants of the district would have to submit to taxation for the purpose.

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In the case of large cities like London and Glasgow, situated on rivers or estuaries, the outfall should be sufficiently far removed to be beyond the action of the returning tidal flow. He was confident that ere long the outfalls for the sewage of London must be prolonged to a considerable distance in advance of the present outfalls.

Mr. LITTLER, Q.C., believed, with the Author, that the sewage difficulty was little nearer solution in consequence of anything that had been recently done. Filth was filth, and must be got rid of, and the best way of doing it was to carry it away as far as possible. Dirt could not be a pleasant neighbour under any circumstances—certainly not unless it could be turned to profit, and at present it did not appear that anybody had made a profit out of sewage, though many persons had lost a great deal by it. He believed no one had been bold enough to produce a balance sheet, which proved that a single penny had been made out of it. In the case of inland towns, of course it was necessary to dispose of the sewage in the best possible way, and in certain instances irrigation farms, where they could be obtained cheap enough, were the best means; but the great objection to that method was, that it was impossible to get the control of the sewage and the management of the farms in one hand, intelligent for both purposes. The sending out of the sewage might be intelligently worked by the surveyor or the superintendent of the local board, but he was not a good farmer; and on the other hand the farmer could not properly control the sewage. Unless the two were worked together, or unless the circumstances were exceedingly favourable, the result would be disastrous either to the public or to the farmer, and in that case the proper person to suffer was the farmer. There was also the further serious difficulty, that unless the farm was under the control of a local board or a public sewer authority, it was likely to be a source of nuisance. Sewage farms might and could be made useful, but until a great deal more was known about them, they were not the best means to be adopted for the disposal of the sewage. It was said that fertilising material ought not to be sent away, but no one had shown that there was any fertilisation to be obtained from sewage compared with the cost involved. With regard to what Colonel Jones had stated as to the value of it treated by pure water, he had had some experience on that point, and the result was that he now declined to treat it at all, because it was so extremely disagreeable unless it was at a long distance from habitations. As to the silting up of rivers, he knew nothing of what might

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happen in Glasgow; but he thought that the broad principle laid down by the Author was correct, and might be carried even farther than he had carried it, namely, that it would be worth while to consider whether the country could not be, to a large extent, mapped out between a number of large sewers, conveying the filth away from the population to the seaboard. He had resided in different parishes on the river Lee, and had, therefore, been, to a great extent, interested in the Thames valley. In one place he was chairman, and in another a member of the local board, and in both cases they had got into trouble with regard to sewage, so that he had watched what had been going on with considerable interest. In one of the parishes most of the experiments with chemicals had proved to be failures, and in the other a similar result had so far happened with regard to farming. He had in his possession some figures showing what had happened in the Thames valley, especially in the immediate neighbourhood of the works of the Metropolitan Board. The first statistics were those of the Metropolitan Board in July 1875. The complaint which caused the report was, that the bed of the river from the year 1861 to 1871 had undergone certain alterations near the main outfall at Crossness. The observation of the Thames Conservancy was, that in the bed of the river where the sewers were discharged between 1870 and 1874, 240,099 cubic yards had been deposited for a length of about $\frac{3}{4}$ mile, and that was in addition to the deposit between 1860, when the works were opened, and 1870, when the attention of Parliament was directed to the question. The real facts were these: Between 1866, when the Metropolition Board poured the sewage in at Crossness, and 1868 there had been a decrease in the deposit of 480,000 cubic yards. From 1868 to 1869 there appeared to have been an increase of 142,000 cubic yards, from 1869 to 1870 a decrease of 216,000 cubic yards, from 1870 to 1871 an increase of 277,000 cubic yards, and in the following year an increase of 279,000 cubic yards; then, oddly enough, in the next year there was a decrease of 260,000 cubic yards, clearly showing that it was owing to accidental causes, not the constant one, sewage, but to other causes, with which no one was more familiar than Mr. Abernethy. In the river Humber the same variations occurred, for which no one could account except by the state of the currents. In 1873–4 there was a decrease in the Thames of 53,000 cubic yards, and in 1874-5 there was another decrease of 100,000 cubic yards, making a decrease of 411,000 cubic yards for the ten years since the time when the sewage was poured into the Thames. Within

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the last year there had been another decrease of 407,000 cubic yards. Mr. Abernethy asserted that there had been a silting up, but the figures just quoted showed the contrary. The statement that the southern channel had been silting up, and that the northern channel had been kept open, simply showed that the current was altering its course. The question whether or not the sewage was filling up the river, was one that could only be dealt with by ascertaining, over a long distance of the reach from Crossness downwards, whether there was an increase of silt, and an increase of sewage deposit. Although Dr. Letheby found some years ago that there was sewage deposit in the bed of the Thames, he did not know that any one had since alleged that there had been any increase of sewage deposit. So far as the best opinions went, there was not so much as there used to be. The Thames mud was specifically heavier than the sewage mud, and the sewage mud did not silt in the course of the sewers themselves, where the velocity was only $1\frac{1}{2}$ mile an hour, while the velocity in the Thames was about $2\frac{3}{4}$ miles. The best way, then, was to regard sewage as a nuisance to be got rid of—to be sent to some place where, though it might not yield a profit, it would cease to be a source of anxiety.

Colonel JONES wished to explain, with reference to Mr. Littler's statement that no accounts had been published showing a profit, that in the report published by the Society of Arts, in the blue book on sewage disposal, and the pamphlet "Will a Sewage Farm Pay?" published by Longman in 1874, full accounts were given of his undertaking.

Mr. SHELFORD said in the past year much printed matter had been produced in connection with the Sewage Question. Sir John Hawkshaw's Report on the Purification of the Clyde was dated 21st March, 1876, and on the 28th of that month two Papers were read at this Institution upon the Utilisation of Sewage, one by Mr. Redgrave, and the other by himself. About the same time Colonel Ponsonby Cox's Report upon the Thames Valley Drainage was published. In May there was a conference on sewage subjects at the Society of Arts, and in July Messrs. Rawlinson and Read reported to the Local Government Board upon the disposal of sewage. All these publications had furnished an immense amount of matter for the composition of such a Paper as that submitted by the Author. He, however, only made one decided recommendation, and that was in favour of those outfall sewers with which the name of Sir Joseph Bazalgette had been for so many years honourably associated. It behoved engineers, therefore, to see

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what reasons were given for arriving at that conclusion. The information obtained during the last few months showed distinctly that the sewage question resolved itself into the difficulty of disposing of the solid matters in suspension. The difficulty of treating the sludge by chemical processes was notorious. In the Paper which he had written, he showed that there was no hope of profitable treatment of the sludge by cheap precipitation processes, but that there might be some chance of profitably disposing of it by what had been called recuperative precipitation processes. In irrigation and filtration it was the solid matter in suspension which fouled the carriers and the land, and blocked up the pores of the filtering material. In the dry earth systems, a great deal of solid matter had to be removed, and it was the expense of that removal which chiefly prohibited the adoption of those systems. In marine and tidal outfalls, the solid matter in suspension must be deposited somewhere, either in the works themselves, or at the nearest point outside the works where still water could be found. This point had not hitherto been much discussed. Mr. Bazalgette appeared to rely to a great extent upon the experience of the outfall sewers of the metropolis, and he stated that "no silting up had occurred there." He ventured to ask whether that statement was made upon the Author's own responsibility, or upon information supplied by some one else. Mr. Littler supported Mr. Bazalgette's statement, and quoted figures to prove that the sectional area of the Thames had not diminished, and that the quantity of soil deposited within a given area had fluctuated considerably. Those figures corresponded exactly with those given last year by Sir Joseph Bazalgette,[1] and he, therefore, in this case also, wished to know whether Mr. Littler had obtained that information himself, or had been furnished with it by others. Even if obtained by Mr. Littler himself, engineers could not admit information and facts on exclusively engineering subjects supplied by gentlemen outside the profession. He had for years been well acquainted with Crossness, and so lately as yesterday he went down the river to examine its present condition. He had had access to the plans of the Thames Conservancy, enlargements of some of which, from a little above the Barking outfall to a little below the southern outfall at Crossness, were now exhibited (Plate 6). It was evident from these that a large deposit of mud had taken place. One of the cross sections had been taken opposite

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlv., p. 192.

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the southern outfall; another opposite Barking; and the third in Woolwich Reach, opposite Woolwich Pier. Those sections showed that a huge bank of gelatinous sewage mud had formed opposite Crossness. Its maximum depth was 11 feet, and when there a couple of men pushed a pole down into it 7 feet without reaching the bottom. Opposite Barking there did not seem to be any great deposit, but there was a considerable divergence from the straight line, and it was possible that the configuration of the shore might account for the absence of deposit. At Woolwich, nearly 2 miles above Barking, the whole bottom of the river was covered with mud of a considerable depth. The sectional area of the river might be the same as it always had been; but that did not get rid of the fact that a large quantity of solid matter in suspension in the sewage was not carried down to the sea, but was deposited in the river. It was to be accounted for, he thought, in this way: The suspended matter in sewage was of a gelatinous, flocculent character. However light it might be, it was deposited, he believed, at slack periods of the tide, outside the works, and, owing to its sticky nature, it there combined with the sand, and when the flood tide commenced, the mixture of sand and sewage was forced up the river, where it became cemented together. It was well known that the tide, at its first flood, acted in a wedge-like way, and disturbed the bottom. That might account for the fact that sewage sludge was found in considerable quantities above the outfall, notwithstanding that the sewage was only discharged on the ebb tide. In proof of this disturbance he might state that samples of the water had been taken during the flood tide, and they showed that whereas it was comparatively clear at the top when viewed through a glass bottle, yet, if taken 7 feet or 8 feet below the surface, it was thick, and full of suspended matter. These facts appeared to show that there were "disturbing causes" affecting the "logical inference" and that it was not a simple question of comparative velocity in the sewer and in the tidal channel. There seemed to be no doubt that sewage could not be discharged into tidal outfalls with impunity, and it was no wonder that Colonel Cox in his Report on the Thames Valley Drainage hesitated, though on different grounds, to sanction a Thames Valley Drainage Outfall Sewer, and recommended instead treatment by irrigation and precipitation of the sewage of places above London. He admitted that in many places outfall sewers might be constructed with advantage, especially near the seaboard. He contended, however, that, when discussing the "Sewage Question"

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engineers must take a broader view, and remember that whilst the works were being constructed science was advancing, and it was just possible, if not probable, that some means might be found for disposing of the solid matter in suspension without loss, if not with profit. If ever that time came, outfall sewers would be unnecessary, and would rank amongst the follies of English engineers.

Mr. SHOOLBRED said, with regard to seaboard and tidal outfalls, that the town and suburbs of Liverpool poured their sewage direct into the river Mersey by about ten outlets, which descended from the heights at the back of the town in a course mostly at right angles to the stream. The town and suburbs of Birkenhead on the opposite side of the Mersey, got rid of the sewage in a similar manner. The deep and narrow gorge through which the river flowed in its passage between those towns occasioned so considerable a scour as to prevent any deposit of sand or other matter at that point; but, higher up, where the river began to widen out, between the Dingle and Garston, and lower down outside the river proper, at Waterloo, also on the Lancashire shore, where the sea channel, confined though it was between sandbanks, was broader than the river near its mouth, and the force of the current was less, a considerable amount of sewage matter had been deposited in the form of thick slimy mud upon what was not many years ago a clear sandy beach. Evidence to this effect had been given before the Rivers Pollution Commission in 1869; and recent information represented the nuisance as considerably on the increase. The town of Southport, about 20 miles north of Liverpool, facing the Irish Sea, and at the entrance of the estuary of the Ribble, also discharged its sewage by several outlets into the sea. Serious complaints had been raised as to the shore being fouled by the sewage, so as to injure the bathing; and the Corporation had decided on removing the whole of the sewage by an intercepting culvert, which was in course of construction, to a point 4 miles higher up the estuary of the Ribble, where it would be poured into the main tideway, and so it was hoped would relieve the town from the nuisance thus occasioned. The large intercepting sewer at Brighton, and works of a similar character at St. Leonards and at other places, had all one object—to get rid of an impending nuisance caused by sewage deposits. Other places there were, and their number was daily on the increase, where the evil had not yet assumed such proportions as to require an immediate remedy; but still the evil existed, and was a growing one. So that a mere tidal outfall was not quite so simple a solution of

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the question as the Author contended. The above facts also disproved the popular saying that, provided the sewage was thrown into the sea it would be carried right away. That this was not the case, these examples proved. This was due to the effect of the tidal action upon the water having been exaggerated and misunderstood. The result of the action of the tidal wave during its progress was to cause a body of water to be impelled along with it until overtaken by the crest period of high water; after which, the force being removed, the water fell back again gradually into its original position, there to await the fresh impulse of a succeeding tidal wave. The movement thus imparted to the water was one of oscillation backwards and forwards, up and down an inclined plane varying in length with the intensity of the particular tidal wave, and certainly not one of translation to a distance. The resultant action of deposit near to the mouths of outlet sewers might also be inferred from the formation of deltas or bars at the mouths of rivers; for outfall sewers were but filthy artificial rivers. The deposit in the two cases might, however, be different both in character and in situation; for, while the river, charged with heavy particles of mud and sand, deposited them, when it came in direct opposition to the tidal current, generally running nearly at right angles to it, the light flocculent matters carried by the outfall sewer, of about the same specific gravity as the water itself, quickly assumed the motion of the tidal stream; slackened speed with it, and with it returned on the flow of the next tide. Thus they were carried about for days, becoming divided and broken up, till at length, on some broader expanse, or in some sheltered bay, where the current was less strong, they were deposited upon the shore. And that deposit was generally strewed along on either side of the outfall, thereby indicating the oscillating action of the tidal current. The indications afforded by floats as to the set of the tide were not always correct. For instance, in the river Mersey, which had two outlet channels, a series of experiments was made some years ago by the then Marine Surveyor of the port, to ascertain the set and rate of the tide. The floats were then all carried down what might be termed the secondary channel; yet the sewage deposits, already referred to as existing below the town of Liverpool, were all situate on the main channel.

Sir Joseph Bazalgette said the discussion had taken a somewhat wide range, and had afforded an opportunity to Mr. Abernethy of reiterating his views, that the sewage outfalls in the Thames had silted up the river, and that the proper remedy was to

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carry them down to the mouth of the river. Although these ideas were unsupported by facts, when Mr. Littler produced the result of careful observations and surveys taken from year to year, and explained the process of increase and scour which alternately went on in the Thames, Mr. Abernethy said, "No, we have heard that before; we do not want to hear it again." So long, however, as he reiterated sentiments without facts to support them, it would be necessary that those figures should be repeated. Again, when Mr. Bateman and Sir Joseph Bazalgette reported upon the drainage of Glasgow, they proposed to carry the outfall to the Ayrshire coast, and not to Clochinch, 5 miles below Greenock, as asserted. In 1869, the Metropolitan Main Drainage Outfalls having been opened in 1866, a similar outcry was raised that the Thames was being silted up, and that the port of London would be closed, so that large vessels would not be able to approach it. That outcry was carried into the House of Commons, and it resulted in the Home Secretary appointing Mr. Rawlinson to inquire into the matter. The inquiry was held, and witnesses were examined, including Sir John Hawkshaw, Mr. Bidder, Mr. Hawksley, Mr. Haywood, Mr. Gregory, and many others. The inquiry was not confined to one single point in connection with the Thames. It embraced the question of Barking Creek, and of the silting up of the main channel of the Thames. He would not go through the evidence given on that occasion, but would simply read some of the conclusions of the Commissioner, in his Report of 1869 (pp. vi and ix): "The balance of evidence is against the assertion that it (the mud) has come from the metropolitan sewage detritus." "That the main channel of the Thames has not been reduced in depth of water by such detritus. . . . That Barking Creek has not been closed to vessels of 250 tons burden." Mr. Shelford had twitted Mr. Littler with having referred to data not prepared by himself. He also stated that he had been down the river to examine it for himself, in order that he might tell the Institution the result of that examination. He surely would not say that upon a single afternoon's visit he had been enabled to see what had been going on in the river for ten or fifteen years previously? Mr. Shelford, however, had exhibited the results of careful surveys. On the other hand, Mr. Littler had referred to the results of careful surveys. It was exceedingly satisfactory to find that the only two bodies who had from year to year made sections of the river Thames were the Metropolitan Board of Works and the Thames Conservators, and that they had been so accurately conducted that wherever they

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could be compared they confirmed each other. He therefore proposed on the present occasion to adopt the surveys and sections taken by the Thames Conservators, and he exhibited three sections mainly representing those surveys (Plate 7). Mr. Shelford had exhibited sections taken in the years 1861 and 1876. The interval embraced a period of fifteen years. But the outfalls of the Metropolitan Drainage were opened in 1866. Why had not Mr. Shelford stated what had taken place before the opening of the Metropolitan outfalls? He now proposed to supply that information, and to show, from the sections made by the Thames Conservators, what had taken place between 1861 and 1867, previous to the opening of the Metropolitan Main Drainage Works. The sections he exhibited showed that within the six years between 1861 and 1867 a larger amount of deposit had taken place than in the nine years between 1867 and 1876. If it were the fact, as proved by those sections, that a large amount of deposit had taken place in that part of the river before the opening of the Main Drainage works, it was also clear the deposit could not have been due to those works; and it was a fair inference that the deposit that had continued to take place upon the bank during the succeeding nine years was due to the same cause as the deposit during the previous nine years, and therefore was not due to those works. Of the sections submitted by him (Plate 7) one had been taken above and another below Crossness Point, and a third opposite Barking Creek, but he had no section which would correspond with the section submitted by Mr. Shelford taken above the works of the Chartered Gas Company. It certainly had never occurred to him to take sections of the portion of the river above the Outfall works, seeing that the discharge of the sewage was upon the ebb tide, and passed down the river. But the subject had received consideration in 1869, when Mr. Rawlinson reported with reference to the bank of mud opposite the new works of the Chartered Gas Company (p. 5): "This portion of the river has not been used for navigation purposes, being out of the main tide-way; and the Admiralty and Thames Conservators having sanctioned the construction of a pier which projects forward into the river, so that this bay will most probably further silt up." Mr. (now Sir John) Hawkshaw, speaking upon the same subject, said (p. 54), "I think it likely that they will diminish in certain places; but" (referring to the mud-bank near the Chartered Gas-works) "I do not think it is likely that that will be diminished, from the fact of there being something in the nature of a groyne put right across it. . . . . I am quite confident that the completion

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of the Chartered Gas Company's pier will increase the mud deposit at that particular bend of the river." Mr. Haywood said (p. 80), the Thames Conservators "would not have allowed that pier to be constructed there if they had deemed that the navigation at that spot on that shore was at all important. If you look at the river it is evident that it is out of the line of the main channel, and is therefore not a matter of importance." He thought the pier and works of the Chartered Gas Company were a far more probable solution of the cause of the bank having been formed above the tidal outfalls, than the assumption that it was due to the discharge of sewage at Barking and Crossness, from 2 to 5 miles below the Chartered Gas Company's works, which passed down the river 15 miles, which was at rest at low water, but which it was assumed was not deposited while at rest, because it had a preference for going back 18 or 20 miles in order to deposit in a reach above the point of the Outfall. That idea was so far-fetched that it required no further argument to show that it was utterly unsustainable. He wished now to direct attention to the section of the river taken in 1833. It would be observed that the river was then much more shallow than at present. It had considerably improved of late years. The scour was also shown, which was much more than the deposit. The channel had really deepened. The cause, he thought, might be well explained. Old London Bridge had been removed about 1833, and that, together with the subsequent removal of Westminster Bridge, got rid of a great obstruction in the bed of the river, admitting of a considerable scour, and causing the general deepening of the river from Richmond to Barking. That was shown by the sections of the Thames Conservators. There were published sections which showed that there had been a gradual deepening and improvement of the river to the present time. It was evident that the removal of obstructions would deepen and improve the channel of the river, and the placing of groynes, or piers, or obstructions at any points would account for any deposits that might take place behind them. It had been said that the dredging of the Thames had had something to do with the improvement of the channel. He had endeavoured to ascertain from the most authentic sources what had really been done in the shape of dredging, but he regretted to say he had failed to obtain the information he desired, and had been obliged to make the best inquiries he could for himself. He believed that the Trinity House had two dredgers, the "Goliath" and the "Hercules," both having been employed at Erith for some years past. The Thames Conservators also had a dredger, called the "Samson," at work at Greenwich;

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but none of those had been at work upon the reach under consideration. A Mr. Williams, who dredged the river for gravel, had two dredgers, the "Queen Bee," at Raynham Creek, and the "Simpson," at work off Crossness. He did not dredge Thames mud, for he could make no profit out of it, but he was permitted by the Thames Conservators to dredge the gravel where he could obtain it, which he did in the main channel of the river. It could not, therefore, be said that London was indebted entirely to Mr. Williams for removing the mud or keeping open the channel of the river. The subject was not now raised for the first time. It had occupied the attention of Mr. Bidder, Mr. Hawksley, and himself twenty years ago; and he would quote their report made at that time to show that the metropolitan drainage was not rushed into in a great hurry, or without full and deliberate consideration. In that report there appeared the following table (p. 68) by Dr. Hoffman and Mr. Witt, exhibiting the condition of the river at six places from Kew Bridge to the Victoria Docks.

Total Amount of Solid Constituents in Grains per Gallon.	River Water.						
	Kew Bridge.	Crab Tree Slip near Fulham.	Opposite Lock at Wandsworth.	Westminster Bridge.	London Bridge.	Victoria Dock.	Mean of these Specimens.
Organic .	1·844	1·992	2·359	1·937	2·194	2·032	2·059
Mineral .	23·067	20·124	23·672	23·496	23·676	25·649	23·281
Total .	24·911	22·116	26·031	25·433	25·870	27·681	25·340

From this it was manifest that the organic matter nowhere exceeded 2 grains in 1 gallon, or $\frac{1}{3500}$, and that it was of nearly the same amount in all parts of the river, and scarcely in excess of the quantity of organic matter to be found in the waters of nearly all tidal rivers, and in many non-tidal rivers, whether flowing from peopled or uninhabited districts. And they said (p. 74), "In considering the causes of the turbidity of the Thames, it should be remembered that the amount of solid matter of every description which is poured into the Thames by the London sewers, is a comparatively insignificant quantity, certainly not greater than 250 tons a-day, a quantity scarcely exceeding that which is cleared out of the docks by manual labour only. The mud incident to the Thames as a tidal estuary, is largely in excess of the mud projected into the Thames by any population on

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its banks; the former is permanent, whilst the latter is perpetually undergoing destructive decomposition." Dr. Letheby at the same time reported that the result of careful chemical and microscopical examinations of Thames water as it flowed by the "Dreadnought" hospital ship at Greenwich made by Dr. Barnes, the senior physician of the ship, and Dr. Odling, showed that the turbidity of the Thames was due to the clay washed from the banks of the river, and that Dr. Odling's conclusion in respect of these analyses was that the foul appearance of the river was not due to sewage but to the clay and other suspended matters. He added (p. 113), "Another fact of importance is that, as we proceed down the river from London Bridge to Gravesend, the turbidity becomes greater and greater, and the amount of organic matter dissolved in the water is progressively increased. Specimens of river water have been taken for me at mid-stream at Higham Creek, Tilbury, Greenhithe, Rainham Creek, Barking Point, the upper ferry at Woolwich, and at London Bridge. The analyses of these specimens are given in No. 3 of the appendix, and they show that when at London Bridge the proportion of organic matter dissolved in the water at high tide did not exceed 2 grains per gallon, at Woolwich it amounted to 2·9, at Barking to 3, at Rainham Creek to 2·8, at Greenhithe to 2·3, at Tilbury to 3·1, and at Higham Creek to 2·7. Similar results were obtained by examinations of the water at each of these places at low tide. And as regards the amount of suspended matter causing the turbidity of the stream, it was found that at high tide the quantity was greatest at Greenhithe, in the proportion of 17·5 grains per gallon, as compared with 2·7 at London Bridge. At low tide the greatest turbidity was at Tilbury, where the quantity of suspended matter amounted to 21·7. These facts showed that the pollution of the river is not caused so much by the matters discharged from the sewers as by the disturbance of the mud that takes place during the tidal movements of the stream, and similar appearances may be observed in every tidal river in the kingdom. If, therefore, it be required that this turbidity should be lessened attention should be bestowed on the banks and the bed of the stream rather than on the sewage which flows into it." And he arrived at the conclusion, that "the turbidity of the river is not caused by the sewage which flows into it, but by the disturbance of the mud upon its banks; for, within certain limits, the farther we go down the river, and away from the influence of the sewage, the greater is the turbidity." Sir John Hawkshaw, in 1869, said (p. 54): "I think there is no better position" for the discharge of the outfall sewers, "if you take the

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question of cost into consideration." He then explained that Captain Galton, Mr. Simpson, and Mr. Blackwell estimated the cost of going 15 or 20 miles lower down the river at £12,000,000, as compared with £3,000,000 or £4,000,000. Mr. Hemans, in 1869, stated (p. 76): "It does not appear to me possible that that mud shoal" at Crossness "can be derived from anything coming out of the outfall. The whole river Thames is full of abrasions. There is a certain amount of mud and grit and sand which is washed from the banks in all directions, and of course there will be deposit in places similar to that where that shoal occurs." He had shown, then, by the evidence and by the sections of the Thames Conservators, first, that the bed of the river had improved of late years; secondly, that the improvement was not due to systematic dredging; thirdly, that the mud banks were not formed by sewage; fourthly, that it would be a wasteful expenditure to carry drainage outfalls down to the mouth of the river at a cost of £10,000,000 or £12,000,000, when a few hundred pounds a year expended in dredging would remove the mud banks which now accumulated in those parts of the river where there was no tidal influence. The last surveys showed that in the reach in question there had been a decrease in the amount of deposit of 411,000 cubic yards since the opening of the Outfall works.

He would now turn to the more immediate subject of the Paper. Its importance could not be overestimated, because one or both of the methods to which special reference had been made must be the means of disposing of the sewage of inland towns, and those methods should be properly appreciated, in order that plans might not be adopted which would only lead to disappointment and to a wasteful expenditure of money. The towns which had been named as the two chief illustrations of the principle of filtration, where the largest amount of sewage had been filtered per acre, were Merthyr Tydvil and Kendal. With regard to the former, in spite of the statements of Dr. Frankland, and of the remarks of Mr. Bailey Denton, he thought the facts and conclusions stated in the Paper remained untouched, and so strongly was he of that opinion that he would not add any observations. But he proposed to make a few remarks with regard to Kendal, the other example of Intermittent Downward Filtration as applied in the case of a large population. It appeared to him that there was an error in dealing with the subject generally. The population of the town had been stated, and also the acreage of the land upon which the sewage was to be poured, and the one was divided into the other without reference to what had been done in the town itself, and the statement was then made

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that the land had purified the sewage of so many persons per acre. Now if it were a midden or cesspool town, he apprehended that the statement could not be correct. If the sewage were otherwise disposed of, it could not go upon the land. He knew it was stated in the First Report of the Rivers Pollution Commission, that the sewage of midden towns was of nearly the same strength as that of water-carriage towns; but upon looking at the tables upon which that statement was founded, it appeared that Liverpool, Manchester, and Salford, which had a great number of houses upon the water-carriage system, were included as midden towns, and Birmingham, which was also called a water-carriage town, had a large number of cesspools and middens, and the amount of water supply to those towns was not stated. The amount of subsoil drainage—drainage passing to the sewers, which caused a large amount of dilution—was not stated. There were also discrepancies in the tables which, in his judgment, prevented a fair average being drawn from them. He was reminded of what took place in London thirty years ago. The metropolis was then drained mainly into cesspools, and it was from the energy displayed by Mr. Chadwick at that time that those cesspools had been destroyed. The ground was saturated with them, the houses were rendered unhealthy, and to prevent those evils the sewage was then turned into the sewers. The result was the pollution of the river Thames, and it consequently became necessary to carry out the main intercepting system. He thought a more just conclusion would be arrived at by assuming that, in the case of midden and cesspool towns, two-thirds of the sewage either soaked away into the ground or was carried to farms and was so disposed of, and that only one-third remained in the form of slops, washings, and refuse to be conveyed to the sewers, and he proposed to apply that principle to Kendal. That town contained a population of 15,700 persons, of whom 3,030 were in direct communication with the sewers, 10,760 being upon the midden or cesspool system; taking one-third of that number, and adding it to the 3,030 would give a total of 6,590. It appeared that of the 16 acres of land, 5 acres had been laid out in filter beds, and 11 acres were used for irrigation. For about one-tenth of the year the whole of the sewage was turned upon the 11 acres for broad irrigation, leaving the sewage of a population of 5,930 persons to be disposed of upon 5 acres of land, or 1,186 persons per acre, for which it was said the land was insufficient. The authorities of the town laid out another 5 acres, making 10 acres for Intermittent Downward Filtration, or 593 persons per acre applied to the filter beds,

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which they believed would be sufficient. At present that was a matter which had not been fairly settled, and the authorities frankly enough said, they proposed to lay out the whole 15 acres in filter beds, showing they had no great confidence that 10 acres would be sufficient. These two examples were no doubt the most favourable under which Intermittent Downward Filtration could be applied. But at what cost had that been done? The land was bought at about £250 per acre, and there had been an expenditure of £305 per acre in laying it out, making a total of £555 per acre. He thought it questionable whether it would not have been better to have carried the sewage of Kendal to a greater distance from the town, where land could have been obtained at a cheaper rate, and then to have applied it upon the principle of broad irrigation, when a larger return would have been obtained. He was far from finding fault with Intermittent Downward Filtration. He thought both systems were desirable and necessary, and it was therefore important that no exaggerations should be imported into the subject, which might lead to disappointment and wasteful expenditure.

The alternative had been to deal with sewage upon one of the dry systems or systems of precipitation. He did not propose to allude to all those systems, whose name was legion, but he would say a word upon the A B C process. It had been stated by Mr. Sillar that that process had been tried in London, and surprise had been expressed that the Metropolitan Board of Works was so silent about the means of disposing of the residue. Sir Joseph Bazalgette was astonished to hear that remark, remembering that Mr. Sillar and himself had broken a lance upon the subject before. According to his view of the London experience the facts were as follows: The A B C process dealt with 11,000,000 gallons of sewage in eighty days, producing 700 tons of sludge at a cost of 25*s.* per ton. When dried into 142 tons, the cost of drying was £6 6*s.* 4*d.* per ton. Mr. Sillar was evidently an enthusiast, but it would not do to be led away by enthusiasm. Whatever chemical value might be put upon the sludge, or whatever Mr. Sillar's notion of that value might be, it was a fact that it remained a drug in the market, and could not be disposed of. If the system were applied to London it would cost 6*s.* 6*d.* per head per annum, or six and a half times as much as the whole amount of the drainage of London. He would give Mr. Sillar credit for having done it at a cheaper rate at Leeds, but there the same amount of purity was not obtained, in consequence of which the system had been given up. About one-third only of the total sewage

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came to the outfalls, and the cost was 2*s.* 6½*d.* per head of the population, or two and a half times the cost of the main drainage of London, taking into consideration the interest on capital, working expenses, pumping, and everything else. It was necessary to take a practical view of the subject, and until it could be shown that the sludge was really of some value and would go towards paying the heavy cost incurred, the advocates of that system could hardly expect it to be adopted. It had been said that sewage sludge had been sold for £10 or £15 per ton, but (he did not apply the remark to any particular body or individual) sewage sold at that price had been "fortified," and was therefore sold for a large sum. It was like putting ten sovereigns into a ton of sewage, and selling it for nine sovereigns, because it would cost one sovereign to take them out again. So the chemical agents put into sewage mud were reduced in value as the bulk increased.

With regard to the Liernur system, he knew that he was treading upon tender ground, for any one who ventured to say a word against it was liable to have personal attacks made upon him. That had been the case with some gentlemen appointed by the Government to report upon the system; but in spite of the castigation they had received, he preferred to take their figures to the figures of the agents of the Liernur Company. It had been stated in a book recently published, that the system had been tried at Leyden, which had a population of 40,000 persons, and applied to twelve hundred out of that population, or $\frac{1}{33}$ part. It had also been applied at Amsterdam to 4,840 out of a population of 287,000, or $\frac{1}{60}$ part. Those two places constituted the main experience of the Liernur system, and the result was that the works had cost £4 per head, or four times the cost of the main drainage of London. The working expenses amounted to 5*s.* per head (but it was thought they might be reduced to 3*s.*), or five times the cost of maintaining the metropolitan main drainage system. Besides, the Liernur system, dealing only with the solid portion of the sewage, did not carry off the water, which must be provided for by another system. By that system the closets in the houses were filled, and the occupants had no control of them. They had to remain filled, in a disgusting state, until some official from the streets turned on a tap, created a vacuum, and drew off the nuisance. That was a state of things which this country would never tolerate. All that he would say with regard to the Liernur system was, that it did not possess the merit even of being "cheap and nasty."

Mr. SHELFORD wished to explain that the plans and sections

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exhibited by him had been obtained from the Thames Conservancy.

Mr. LEMON said he thought the gentlemen who had written the Report referred to by Mr. Adam Scott could know little about the subject, speaking as they did so decidedly about it, for all scientific men were agreed, that the more they studied the question the greater were their doubts concerning it. The Author had stated, with regard to the precipitation process, that no chemical process could efficiently deal single-handed with sewage, but must be assisted by some artificial means. He agreed in that, but was not prepared to make such sweeping assertions as were contained in the Paper. There were places where the precipitation process might be regarded as a choice between two evils. Taking the case of Birmingham, he did not suppose that any local authority had bestowed more pains to ascertain what was the right system to adopt than had the local authority of that town. They went to Parliament to acquire land, but were beaten on a division in the House of Commons by the votes of the landholders themselves—a circumstance unparalleled in the history of sanitary legislation. They then went to Mr. Hawksley, who advised them to adopt the lime process, as he thought any other member of the Institution would have done under similar circumstances. With regard to the application of sewage to the land, he quite agreed that that was the right course, especially when sewage was discharged into a potable stream, but he thought that the data laid down as to the proportion of sewage to an acre were fallacious. The basis upon which the quantity should be estimated should be, not the proportion of the population to an acre, but the number of gallons discharged upon an acre. The sewage or the dry-weather flow of towns varied considerably, ranging from 17 gallons per head in the case of Blackburn to 64 gallons in the case of Warwick. The average of all towns was about 33 gallons, including subsoil drainage. He did not think that engineers paid sufficient attention to the question of subsoil drainage. They believed that the drainage would find its way by the sewers, and so it did as a rule, but that was rather a slovenly way of dealing with that question. If there was a large amount of subsoil water it ought to be faced boldly, and dealt with on an efficient system. In Winchester, which he had just laid out, there was a large amount of subsoil water, and he had devised a method by which it would be discharged into the river at all available points. With reference to the amount of drainage or dry-weather flow stated in the Report of the Royal Commission as discharged on land, he observed that a

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large amount of it was subsoil drainage—at Kendal 350,000 gallons out of 750,000, or nearly one-half; at Warwick one-third was subsoil water; at Rugby 150,000 out of 400,000 gallons; at Bedford 300,000 out of 700,000 gallons. When such an enormous quantity of subsoil water was discharged on a sewage farm it greatly increased the difficulty of dealing with the sewage.

As to tidal outfalls, he had carried out works on tidal streams, and could not indorse the opinion expressed by the Author. He did not think that throwing the sewage into the sea was the right thing, even under the most favourable circumstances. The most favourable place he had seen for the discharge of sewage was Portsmouth, where it was sent out at a great velocity. At Southampton, where the sewage was discharged into Southampton Water, he had constructed some works, about ten years ago, somewhat after the Metropolitan model, discharging the sewage on the ebb tide, as in the case of the Thames. The position was more favourable than Crossness or Barking, because the ebb tide discharged it at a greater velocity; but even under those favourable circumstances there was a deposit at the outfall, which had to be occasionally removed by dredging. That was a pretty good proof that something more was required than flushing the washings of the sewers into the sea. At Barking there was a fall towards the outlet, and arrangements were made, by flushing-culverts and otherwise, to flush the deposit into the river. That he maintained was a wrong principle. He had had ten years' experience of it, and he was now adopting a different principle in some other works not far off, making tanks, intercepting and not encouraging washings or flushings of the deposit into the river. He thought that all outflow tanks should be lowest at the inlet, and that the mud deposited by the outfall sewer should be pumped out by a mud pump or other means, and not be flushed into the rivers. It was clear to his mind that, in consequence of the inefficient means adopted in London, a large amount of detritus must be washed into the river. If proper means were adopted to intercept the silt, either by a systematic removal of the deposit in gullies, or by better arrangements at the outfall tanks, there would not be that deposit in the river which was said to exist by Mr. Abernethy, but denied by Sir Joseph Bazalgette.

Mr. Bazalgette, in reply, said the first remark that called for any comment was one made by Mr. Shelford, who stated that several publications—and, amongst others, the recent report of the Local Government Board—afforded abundant matter for the compilation of a Paper such as had been read. He did not dread

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the suspicion of plagiarism; but if Mr. Shelford had looked at the first page of the Paper, he would have found that it had been lodged in the hands of the Secretary of the Institution before he could have had access to that report. It was, however, a remarkable fact, going far to corroborate the soundness of the conclusions which he had ventured to lay down, that those who were much more qualified to judge upon the subject than himself, had, by an independent process of reasoning, and by the aid of different materials, arrived at conclusions almost identical with his own, so far as they had travelled side by side. As to Mr. Shelford's remarks with regard to Mr. Littler, he had felt that the burden of the discussion was too much for him to bear; and Mr. Littler, therefore, had, at his request, replied to Mr. Abernethy upon the question of tidal outfalls. Mr. Shelford had asked whence Mr. Littler obtained his information. Was it outside the walls of the Institution? because if so, he must deprecate the idea of a person who was not an engineer or an expert obtaining information from outside, and then using it as though he were an expert. But although Mr. Shelford had laid down that rule, he was himself the first to transgress it; for he stated that he had had access to the plans and sections of the Thames Conservancy, in the same way as Mr. Littler had had access to the plans and sections of the Metropolitan Board of Works; and he proceeded to argue from his information in the same sense as that in which Mr. Littler had argued from his. Dr. Frankland had remarked upon a statement in the Paper that much progress had not been made in the sewage question, so far as discovery and invention were concerned, within the last quarter of a century, and that it was not likely that much progress would be made within a corresponding period, and he had called that statement an ungenerous one. But what was the fact? Taking the systems one by one, the lime process was introduced a quarter of a century ago at Leicester; and it had been stated in the course of the discussion that any member of the Institution would have recommended at Birmingham, if he had been in Mr. Hawksley's position, the same process in operation there now, namely, the lime process. Could it then be said that chemicals had made much progress? Then with regard to irrigation, he might be accused of eccentricity or quaintness if he referred to the 'Mishna,' in which it was stated that Jerusalem at one time sent its sewage down the valley of Kedron, where it irrigated the King's Gardens, and was there collected in tanks, and the solid matter sold to the gardeners in the neighbourhood for a trespass offering: so that the best form of irrigation as practised in the

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present day was practised at Jerusalem. But without going back to such ancient days, irrigation was practised upon the Craigentinny meadows more than a century ago. With regard to tidal outfalls, one gentleman learned in sewage botany had described the absorption of sewage by different plants, and had spoken of the effects of tidal outfalls with regard to Rome and the Cloaca Maxima, Samsoon on the Black Sea, Smyrna, and Ephesus. As to the dry earth system, he need hardly say that it was as old as the feline race. His remark that there was not likely to be much progress in future was not made without an object. A feeling appeared to be prevalent among sanitary authorities that some miraculous intervention would take place to enable them to arrive at a solution of the sewage question so that it might be set at rest. Resolutions had been adopted and speeches made by prominent members of local boards, such as that at Leeds, where the A B C system had been tried up to the last moment, stating that they were in hopes that further discoveries would set their doubts at rest. He ventured to think that that waiting upon Providence had a most mischievous effect. The subject had been fairly exhausted; and if local boards and sanitary authorities would only make up their minds to grapple with it as it stood, and avail themselves of the materials at hand, they would be doing much better than leaving the question to the Great Unknown.

With reference to the first division of the subject, that of chemical treatment, he had, in a sense, arraigned many processes, not to condemn them, or in any partisan spirit, but to determine what was the proper province of chemistry with regard to the treatment of sewage. Only two or three speakers had answered the arguments he had put forward. The points he had mentioned in detail had not been taken up; and in very few instances had anything like an inaccuracy been pointed out. Mr. Sillar had not dealt with one of his arguments. His method of meeting them was remarkable. He had exhibited a paper containing a sample of dry sewage manure, and also a bottle containing a fish in a state of exuberant vitality. Months had passed, he said, since the water had been taken, and that he regarded as a proof of its purity. Mr. Sillar called it water, but Mr. Bazalgette called it sewage, and he believed if it had not been sewage the fish would not have been alive after so long a time. If Mr. Sillar would take an excursion down the Thames upon a sunny day, he would find abundance of fish, at the places where sewers discharged into the river, feeding upon the sewage as if they liked it. If Mr. Sillar pointed to the fish as a standard of purification, it was certainly not a standard

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that would be accepted by the Thames Conservancy. As for his sample of dried sewage manure, it was easy enough to produce such a specimen, and it had been done over and over again. Those who gave evidence upon the Birmingham Sewage Bill might remember a witness from Rochdale, who came with his coat tails literally crammed with samples of dried sewage manure, which he produced one by one and submitted to the Committee. It was easy enough to produce a fæcal cake; but the difficulty was, when it was produced, how to dispose of it. At Leeds, where the A B C system was in operation, an enormous amount of accumulated sludge, or manufactured sewage manure, had been left upon the ground. Why was that, if it was so valuable and commanded a ready sale? What he desired to look at was not the chemical valuation, but the real value which the thing possessed. It appeared that the Corporation of Leeds had contracted to dispose of this sewage manure for 12*s.* a ton, a price wholly inadequate to defray the cost of treatment. As to the remarks of Mr. Crookes, he had not claimed to be an authority, but had only brought forward facts and conclusions to enable others, if they could, to expose their inaccuracy. Instead of doing this, Mr. Crookes, after shelving the experience of the past, had entered into a learned theoretical dissertation upon the merits of chemicals, and, above all, of alum, blood, and charcoal. It would have been better if an explanation had been given of the shortcomings of the A B C process, as stated in the Paper, and of the reasons why it had been abandoned in many towns. As to the observations upon second-hand or derivative knowledge, he would merely remark that, until reminded to the contrary, he had thought all knowledge was more or less derivative. The report of the Rivers Pollution Commissioners would bear out the expression that their conclusions as to the A B C process were "based upon the most irrefragable evidence." So far from agreeing that the A B C process was the system of the future, he believed it was one of those systems which by experience had been deprived of exaggerated excellence, and had been reduced to a more appropriate level. At Crossness, indeed, the sewage was purified sufficiently, but in that case there was a bankrupt expenditure.

On the subject of irrigation he desired to correct one mistake. He had stated that, though no profit could be made from the cultivation of crops by the sanitary authorities, a moderate profit might be made by the farmer. But in his final conclusions he had stated without any qualification, that no profit could be expected from the cultivation of crops, and he now desired to correct that in accordance with

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the previous statement. With reference to the value of sewage as an irrigant he wished to say a few words. He had said that no less than 70 per cent. of the nitrogen contained in the sewage ran away in the effluent, leaving only 30 per cent. of fructifying matter to the credit of the crop. Dr. Frankland said that was an extreme case, and that though the inference was fair, yet taking the analyses as a rule, it would be fairer to say that one-third of the fructifying matter passed away in the effluent. If that view had only been started for the purpose of obtaining such an admission from so eminent a chemist he should have been satisfied. Mr. Hope had stated that 10 per cent. of the nitrogen was the amount passed away in the effluent in his farm; but Dr. Frankland said, as the result of general experience, that one-third passed away. It appeared that he (Mr. Bazalgette) had not carried the analysis, which was that of Dr. Frankland, quite far enough. It was true the 30 per cent. might not in the shape of carbonate of ammonia, having become volatilised, pass away into the air. But what was the case with chlorine? It was not abstracted by the soil, and not added to by the subsoil water, and it ought therefore to be found in the effluent in about the same proportion as in the sewage: but in the sewage it was 22·1, and in the effluent only 13·4. What was the reason for this reduction? Clearly, dilution. Applying that to the nitrogen it would appear that the 30 per cent. credited to the crops was more than disposed of by dilution. Taking the table as it stood, it was remarkable that little or no nitrogen, or *minus* nitrogen, had gone to the plant. With reference to downward filtration, if that were a chemical issue he should consider it presumption on his part to enter the lists with Dr. Frankland; but as Dr. Frankland had supplied the data from which the inferences might be drawn, it became a simple question of common sense and arithmetic, and therefore he ventured to differ from him. But before referring to the actual figures he thought that some margin ought to be left for the unreliability of laboratory experiments. In performing an experiment, Dr. Frankland selected a particular soil, and packed it layer by layer in a glass vessel, thus getting rid of the irregularity of composition found in the actual filter bed; there was no accidental substratum of clay here and there; all was regular and even. Then the fact of packing the soil and agitating it loosened it to a certain extent, so that it was in that respect different from the soil of the filter bed. In order to get the sewage he put a bucket into the sewer and drew off the top waters, avoiding all those heavier

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matters which floated towards the invert and went upon the farm, tending to clog the pores and impede filtration. Again, in pouring the sewage upon the artificial filter he did not pour in the way in which it went upon the natural filter bed, half the daily quantity going in six hours, but he distributed it evenly, weighed out the chemicals, and gave each particle of sewage its right proportion; thus there was not the rough-and-ready sort of admixture that took place when the chemicals were simply placed in a depositing tank with the sewage and stirred up together. The process went on quietly. But where was the rain that flooded the farm and impeded filtration? Where the sun that drew off exhalations? Where the wind that wafted them to contiguous habitations? Those disturbing elements were absent; and the result of the laboratory experiment was more favourable than could ever be obtained under the conditions of nature. He had, however, made no deduction on that account in testing the accuracy of the experiments. But to come to the direct issue, the Rivers Pollution Commission, in their first Report, pp. 63–69, had set out the detailed results of six experiments by Dr. Frankland, showing the effect of the downward filtration of London sewage through various kinds of soil. On the faith of these experiments they had advanced the proposition that the sewage of 3,333 persons could be permanently purified upon a single acre of soil, drained 6 feet deep. He, on the other hand, maintained that the experiments only justified a proportion of less than 2,000 persons to the acre, and that, consequently, about 1,500 persons to the acre had been added by the Commissioners above the proportion warranted by the experiments. Dr. Frankland had defended the conclusions of the Commissioners; and which was the correct view was now the question. He had treated the experiments in this way. He found that six had been set out in the report, and that in each case the result of the experiment had been to show that, up to a certain point, purification could be effected, but that beyond that point purification began to fail. The first point, for the purpose of his argument, he called a positive result, and the latter a negative result. Now, as the Commissioners, in advising a proportion of 3,333 persons to the acre, were speaking with reference to permanency of effect, it was clear that the negative results, where purification was falling off, ought not to have been taken into account as inducing such a conclusion. To test the Commissioners' proportion, he had discarded the negative results and simply dealt with those which indicated the extreme point at which purification could be properly effected; and, considering

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that it was a standard laid down for permanent and practical use which was in question, and not a merely theoretical idea, he thought it could hardly be said that, in refusing to consider the negative results, he was not dealing fairly by the experiments. Taking, then, the mean of the positive results of the six experiments, he found that purification was effected at the rate of 5·9 gallons per cubic yard of soil in twenty-four hours, or in the proportion of less than 2,000 persons to the acre, drained 6 feet deep. Thus the Commissioners, in mentioning 3,333 persons to the acre, were about 1,500 over the mean, and even in excess of their highest positive result, which was 9·9 gallons per cubic yard in twenty-four hours. Dr. Frankland had, accordingly, to account for an addition of 1,500 persons to the acre above what Mr. Bazalgette said the experiments warranted. How did he set about this task? First, he began by rejecting all those experiments which would not support the desired result. Three out of the six experiments were thus cast aside. In the case of the first experiment, through sand and chalk, the glass vessels were too small; in the case of the second, through peat, it was undertaken purely in the interests of science; and in the case of the third, through Barking soil, it stuck in the cylinder so that the purification was unsatisfactory. Hence Dr. Frankland argued that, out of the six experiments, these three must be laid aside, before proceeding to test the accuracy of the conclusions which had been founded upon them. But there was not a word about this in the report. Not a word to show that a process of selection had been employed. On the contrary, the Commission, in speaking of these experiments, invariably referred to them in a collective sense. If they did not support the Commissioners' conclusions, he would ask why they were set out in the Report, and referred to with the remaining three experiments, as the collective bases upon which their conclusions were founded? But even after Dr. Frankland had employed this process of rejection and selection, he was still far from having accomplished the desired end. For, taking the positive results of the three selected experiments—9·9 gallons per cubic yard in twenty-four hours, in the case of the Dursley soil; 7·6 gallons of the Beddington soil, and 4·4 gallons of the Hambrook soil—their mean showed that purification could only be effected at the rate of 7 gallons per cubic yard in twenty-four hours, or in the proportion of about 2,300 persons to the acre drained 6 feet deep. Even with the three selected experiments Dr. Frankland had still to explain, with regard to the statements of the Commission, an error of 1,000 persons above what the mean would justify. No longer confining himself to the posi-

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tive, he was obliged to have recourse to the negative results of the experiments, and to import them into the calculation upon which the Commission had founded their conclusions. Surely, if he stopped there, having directed attention to the fact that Dr. Frankland had now been forced to admit that the Commission, when they had laid down a practical standard of 3,333 persons to an acre drained 6 feet deep, had taken into account the results of experiments, where purification had actually failed, he would have justified the assertion made in the Paper, that those experiments had been strained beyond their legitimate effect. But he must follow Dr. Frankland's reasoning a step further, for there was so much contradiction between the statements in the First Report and in the discussion, that it was absolutely necessary to refer to this discrepancy. He would take the three soils selected by Dr. Frankland, one by one, and compare the language used in the First Report of the Rivers Pollution Commission with the language used in his recent argument. With regard to Dursley soil (p. 69 of the Report), Dr. Frankland had said, "One cubic yard of Dursley soil" can cleanse "no less than 9·9 gallons in twenty-four hours." "Even when the rate of filtration amounted to 12·4 gallons per cubic yard in twenty-four hours, the sewage was greatly ameliorated, though not quite satisfactorily cleansed." But in the discussion he had taken into account the negative result, 12·4 gallons, where the sewage was "not quite satisfactorily cleansed," for the purpose of supporting the Commissioners' conclusions. Secondly, as to the Beddington soil. In the Report (p. 65) it was shown "how satisfactorily the sewage is purified even at the rate of 7·6 gallons per cubic yard of soil per diem. But when this rate was doubled the nitrification ceased, and the pores of the soil became blocked up so that they would no longer transmit the whole volume of sewage supplied and also afford time for aeration." Contrast this with what he had said of this soil in the discussion: "The Beddington soil purified with the greatest readiness 7·6 gallons of sewage per cubic yard of soil" (*ante*, p. 193). Here the words, "with the greatest readiness," in the discussion were substituted for "even at the rate of" in the report. Thirdly, Hambrook soil. The contradiction here was complete. In the Report (p. 69), it was said: "Whilst one cubic yard of sand or of Hambrook soil cannot continuously and satisfactorily purify more than 4·4 gallons of London sewage per twenty-four hours," &c., in the discussion it was: "The Hambrook soil, which was inferior to the others, purified most efficiently 6·2 gallons per cubic yard in twenty-four hours" (*ante*, p. 193). He would leave it to Dr. Frankland to explain the difference between 4·4 and 6·2, for he

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could not. He would ask if this was the right way to deal with laboratory experiments for the purpose of founding a practical conclusion. First to reject; then to select; then to take the highest extreme at which purification could be effected, and to add to that three other results—(1) sewage not satisfactorily cleansed; (2) filter ceased to act; (3) purification absolutely ceased—for the purpose of raising the mean result as high as possible. Were these results present to the Commissioners' minds when, in their Third Report (p. 51), they wrote, "The laboratory experiments, on which we build our confidence in filtration thus conducted for cleansing sewage, may be considered conclusive as to the satisfactory and permanent efficacy of the remedy thus provided." Yet such was the argument pursued by Dr. Frankland to support what Mr. Bazalgette had ventured to call the exaggerated standards of the Commissioners; and he now submitted that this method of reasoning—if indeed it was that which had induced Dr. Frankland and the Commissioners to lay down such standards—established the exaggeration out of their own mouths. But Dr. Frankland's argument was not merely unsound; it was also an after-thought, which had never occurred to Dr. Frankland previously to his speech, as he would show. On p. 69 of the Report, Dr. Frankland had stated: "These analytical results show that, the Dursley soil surpasses all the others experimented upon, in its power of purifying sewage." Now the highest positive result of Dursley soil was 9·9 gallons; and the next highest was that of 7·7 gallons, in the case of Beddington soil. Thus the Commissioners, as the above passage proved, must, in laying down their standards, have been speaking with regard to the positive and not to the negative results of this experiment, for the above statement became untrue when the negative results were imported. In the discussion, however, by introducing the negative results, Dr. Frankland had got Beddington up to 11·4 gallons, as compared with Dursley 11·1 gallons, and so had made Beddington surpass Dursley as to its purifying power, in direct contradiction to the above statement in the Report. Other remarks in Dr. Frankland's speech called for brief comment. He had complained that the Paper had stated that the Commissioners, in speaking of Merthyr Tydvil, had placed it on record that the sewage of 50,000 persons had been pumped on 20 acres. This record he had asserted to exist only in Mr. Bazalgette's imagination. Upon p. 131 of the Paper, the authority had been given for that statement. Dr. Frankland seemed inclined to think that a subsequent passage in the report, referring to the fact that rather more than one-

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third of the inhabitants were connected with the sewers, had sufficiently qualified and explained the Commissioners' statement, and reduced the proportion of population to acreage to only one-third. Such an answer might be a good one if it were urged by or on behalf of any one except the Rivers Pollution Commissioners, of whom Dr. Frankland was one; for in the same Report (pp. 23–30) they had taken the most elaborate pains to prove, in comparing the midden with the water-closet system, that connection with the sewers did little or nothing to reduce the sewage in volume or strength. Hence the so-called qualification was, coming from the Commissioners, no qualification at all, and the correction of Dr. Frankland, as a Commissioner, a correction which was inconsistent with the views to which he stood pledged; for it was impossible that he could be allowed to use the same argument to prove two exactly antagonistic conclusions. With regard to what Dr. Frankland had said upon the subject of the analyses of the Merthyr sewage and effluent, as showing that deterioration in the quality of the effluent was taking place, he would only observe that these analyses had not been carried to their proper extent, for, in the results, the dilution of the sewage by infiltration of subsoil water, and water from the Taff, had not been considered. Mr. Henry Law, however, had dealt sufficiently with this question.

Before leaving the consideration of Merthyr, he would correct another inaccuracy of Dr. Frankland's, who had affirmed that, when Mr. Harpur had spoken of a proportion of 500 persons to the acre as representing the limit of safe application, he was speaking not of the capacity of downward filtration, but of the largest proportion which ought to be adopted consistently with the growth of the crops upon the filters. But what Mr. Harpur had said was this: "I do not think it would be safe, generally, to place more sewage than that of 500 to the acre." Now would he talk of "safety" if he were speaking merely of crops? or was he not rather referring to the purifying power of the soil? This answer of Mr. Harpur's should be read in connection with the context on p. 137 of the Paper. Dr. Frankland still seemed to think that downward filtration was a discovery, and had attempted to show that he was a discoverer in the same sense as Gossage, Reichenbach, and Young. True, these men were real inventors, and yet mere imitators of nature. But Dr. Frankland seemed to argue that any imitation of nature was necessarily an invention. As for downward filtration, he had yet to learn that putting in drains to the depth of 6 feet, combined with an intermittent distribution of sewage, was an invention in any true sense of the term. One

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passage more from Dr. Frankland's remarks, and he would pass to Mr. Bailey Denton. It referred to downward filtration, and was to this effect: "This process the Author spoke of rather contemptuously, and laboured hard to prove, first, that it was not new; secondly, that it was not true; thirdly, that it never had, and never could have, any existence; and then, somewhat inconsequently, concluded by recommending its adoption" (*ante*, p. 191). Dr. Frankland, subject to one slight qualification, could have scarcely summed up his case better for him. Downward filtration was not new. Downward filtration was not true, in the sense in which it appeared in the Commissioners' Report. As regarded the third statement, he would ask Dr. Frankland to restore the words which he had omitted when he made the Author come to the conclusion that downward filtration "never could have any existence." He would find them on p. 158 of the Paper; they were, "Intermittent Downward Filtration, as expounded and explained by the Rivers Pollution Commissioners, has never had and never can have any practical existence." With that qualification, he adhered most strictly to the statement.

With regard to the remarks of Mr. Bailey Denton, who had said that he was content with the Author's conclusions, but totally rejected the means by which they were arrived at, he observed that, as no reasons for the rejection were given, he presumed that the means would stand. Mr. Bailey Denton likewise said that the important question was, not whether the sewage of 500 persons could be applied to an acre, but whether crops could be grown so as to afford relief to the ratepayer. Mr. Bazalgette ventured to think that purification came first, and profit second; but Mr. Bailey Denton appeared to think otherwise. A question had been raised as to whether the measurement of the beds at Kendal was 4½ acres or 5 acres. He had, however, a letter from Mr. Banks, the Surveyor, which quite corroborated his statement. His remarks with regard to Kendal and Merthyr, and other available experience of downward filtration, remained totally unchallenged. As to the profit of crops, he would leave Mr. Bailey Denton in the hands of Mr. Henry Law, who had fully dealt with that subject. Mr. Field had said that the works at Merthyr Tydvil might have been carried out at half the cost if they had not been made two or three times over. If that were so, how did it happen that, according to Mr. Rawlinson's report, the works at Merthyr cost £230 per acre, while those at Kendal cost £280 per acre? He thought that the explanation would be found in a letter he had received from Mr. Baldwin Latham, who had been

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to Merthyr with the view of advising the Aberdare authorities as to carrying out a joint scheme of sewage disposal with that town. The letter was as follows:—

"For the last fortnight I have had, and still have, under consideration, questions relating to the Merthyr sewage farm, and I have been very surprised to hear in the course of the discussion the misuse which has been made of Mr. Harpur's name. I have known Mr. Harpur for many years as a man of great experience in matters relating to the construction and working of systems of sewerage and other sanitary works, and his experience is of a far longer and more general character than that of those who have attempted to dispute the facts with which he has supplied you. I have always found Mr. Harpur to be an honourable member of a noble profession, and what he has stated with reference to the intermittent filtration area at Merthyr may be taken to be absolutely correct. With reference to these filters, I may inform you that, on my recent visit to the Merthyr sewage farm, I found that they were being dunged with solid manure at a rate exceeding 20 tons per acre; in fact they are not used as filters at the present time, except in the sense that all the rest of the land is so used, for although a large sum of money has been expended in laying out these filters, it is found by experience that there is land on other portions of the Merthyr Board's farm which is far more efficient as a filter than these artificial filters. With reference to the construction of these intermittent filters, the nearest drains are 60 yards apart, and in the sense in which they are called filters, every arable field which has a ditch on three sides of it may be equally called a filter. I found the water was standing within 2 feet 8 inches of the surface in the centre of the plots, the side drains being 6 feet deep and the bottom drain 8 feet deep. The volume of effluent water flowing off the plots greatly exceeds the volume of sewage turned on to them, and when there is no sewage turned on to them, there is still an effluent flowing from them. With the relative volumes of 4 of subsoil water to 1 of sewage, it is clear that even without the aid of land or other agency, the mixture would show, by analysis, a diminution of 80 per cent. in the amount of polluting matter. The circumstances at Kendal are not unlike those at Merthyr. It is a well-known fact, in selecting an area for irrigation in counties which are noted for excessive rainfalls, given a piece of land upon which water does not stand after rain, it will take any amount of sewage. A system of disposing of sewage on very limited areas may simply become a mode of discharging sewage by 'concealed outfalls,' instead of a system of purification.

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"The general conclusions which I draw from a perusal of your Paper are in accordance with my experience extending over a long period and under varied circumstances. There is one remark which I should feel disposed to cavil at, and that is where you class all persons who have patented systems of purifying sewage as 'empirics.' An historical record of the processes of treating sewage by mechanical and chemical means would include the names of some of the first engineers and chemists of their day, and I think they are entitled to a different classification to that to which you have relegated them."

In the strong light of that evidence, he imagined that the Merthyr scheme must crumble to pieces. With regard to Mr. Baldwin Latham's concluding remark, that he made the term "empirics" apply to men of honour and eminence, he much regretted that the necessity of terseness in his introduction could have laid it open to such a construction. Once and for all he would wish it to be distinctly understood that, while fully appreciating and desiring to do honour to the genius and energy of chemist and engineer, he had meant to apply the expression merely to those who, time after time, for private advantage, had floated bubble companies and paraded worthless chemical baubles in the gaze of the public, resulting in disappointment and loss.

In Kendal, the proportion of sewage going to the filter beds was stated in the Paper to be one-third of the total sewage of the town, which was enough, considering that there were only four hundred and fifty closets in the town. In the first place, there was a regular system of scavengering, and the middens were cleared out whenever they were liable to overflow. The Rivers Pollution Commission reported that in all middens leakage into the soil took place; and, under the circumstances, he ventured to think that crediting one-third of the sewage to the filter beds was more than sufficient.

In defence of the dry systems, Professor Ansted had referred to the pail system in use at Manchester, declaring that, "as far as he could detect, it was not a nuisance." The question of what constituted a nuisance was of course a matter of opinion and degree; but the Rivers Pollution Commission did not seem to agree with Professor Ansted in his view of it. Speaking of Manchester, they had said, in their first Report, pp. 23 and 24: "In spite of district inspection under an energetic and experienced chief, in spite of police assistance, and notwithstanding that the penny post enables every householder so easily to give notice to the scavenger, privies and ashpits are continually to be seen full to overflowing and

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as filthy as can be. . . . . These middens are cleaned out whenever notice is given that they need it, probably once half-yearly on an average, by a staff of night-men with their attendant carts. Occasionally twenty or thirty 'middens' are thus cleaned out in succession, the contents being wheeled along the whole length of the row, making the air offensive for several nights together, and creating a nuisance, none the less injurious because, the work being done when the people are asleep, the filthy smell is not perceived." Possibly the explanation might account for Professor Ansted not having observed the nuisance. He had also complained that London was not a fair test place for the application of the dry earth system. That might be so, but it served the purpose of illustration well; in fact, he had stated in the Paper that the applicability of the system was in the inverse ratio of the increase of population. Hence London was the most unsuitable place of all. He would pass over the Liernur system in silence, for, as his remarks in the Paper upon it remained absolutely unanswered, he did not think they would gain force by repetition.

Tidal outfalls had also been sufficiently dealt with, and he thought that the metropolitan outfalls had been completely exonerated from the charge of silting up the channel of the river. Mr. Shelford had fallen into one error—he had said that Colonel Cox, in reporting adversely to the Thames Valley outfall scheme, had been influenced by the supposed effect of such an outfall upon the river Thames. Having been personally engaged in the inquiry which resulted in Colonel Cox's report, and having that report with him, he ventured to state in the most emphatic manner, that there was no ground for alleging that consideration of the injurious effect of such an outfall had been present to Colonel Cox's mind when he made that report. On the contrary, having first stated that the scheme was too large or too "heroic" for the requirements of the district, in which opinion Mr. Bazalgette ventured to differ from Colonel Cox, he recommended that irrigation should be the mode of disposition for some places and chemicals for others, the recommendation being based alone upon the relative position of such places with regard to the intake of the water companies, and in no way having reference to the subject of a tidal outfall. Mr. Hope had also fallen into some grave misstatements with regard to the effect of the metropolitan outfalls on the town of Barking. He had made three distinct allegations, neither of which had any foundation in fact. The first was that there was a disagreeable odour in the neighbourhood of the outfall, which was due to the

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outfall. Dr. Letheby had inquired into the accuracy of that statement some years ago, and had conclusively shown that the odour of which Mr. Hope had spoken was produced by certain bone-boiling and other establishments, where offensive trades were carried on in the vicinity of the outfall, and not by the outfall itself. The second statement was that the effect of the outfall had been to produce a fever epidemic in the town of Barking. Now Mr. Rawlinson had held an exhaustive inquiry upon this subject, and came to the conclusion that such epidemic was caused solely by the defective sanitary condition of the town of Barking and could in no way be attributed to the outfalls, which were 4 miles distant from the town. He would also remind Mr. Hope that it was at this time that his company for financial reasons had failed in their project to carry the metropolitan sewage to the Maplin Sands, and were, consequently, most anxious that it should be carried there for them at the public expense. This being so, it was pretty well understood at the time that the outcry against the metropolitan outfalls was one which had been got up in the interests of that company. At any rate he was surprised that Mr. Hope should revive statements prejudicial to the outfall, when he was aware that they had been completely disposed of and contradicted by independent official investigation. The last statement which Mr. Hope had made was as unfounded as the first two to which he had referred. It was to this effect: "It was a common mistake to suppose that Parliament had ever sanctioned, or that Sir Joseph Bazalgette had ever designed, the outfalls for the permanent disposal of the sewage of London" (*ante*, p. 181). While he maintained that, if there was any mistake, it was that of Mr. Hope in making such an assertion, he challenged him to produce a single tittle of evidence in support of it. One other remark, and he had done. Several speakers, including Mr. Shelford and Professor Ansted, had commented somewhat forcibly upon the fact that he had only made one recommendation, namely, that in favour of tidal outfalls. He ventured to think that he had made four distinct recommendations, and, with the sole exception of the Liernur, had assigned to every system which he had considered an appropriate place in the disposal of sewage.

*** Owing to the length of this article and its position in the volume, it has been necessary to omit several contributions received through the Secretary. These will be given in the next volume, but will appear at once in the pamphlet edition of the article. The names of the contributors are: Mr. T. W. Keates, Mr. John Wrightson, Mr. Eachus, Capt. L. Flower, Prof. Tanner, Mr. J. Newton

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Mr. B. S. Brundell, Mr. H. Robinson, Mr. J. C. Melliss, Mr. W. Atkinson, Mr. Mansergh, Dr. Voelcker, Mr. Hassard, Mr. A. Jacob, Dr. Pole, Mr. R. W. P. Birch, Mr. Jas. B. Alliott, Mr. R. Aitken, Mr. W. Donaldson, M. Mille, Mr. Brunlees, and Mr. Gower.

February 13, 20, and 27, and March 6, 1877.

GEORGE ROBERT STEPHENSON, President, in the Chair.

THE discussion upon the Paper, No. 1,506, "The Sewage Question," by Mr. C. NORMAN BAZALGETTE, occupied each of these evenings.

The following Candidates were balloted for and duly elected on the 6th of March:—WILLIAM ANDREWS, HENRY MARC BRUNEL, and ARTHUR WILDMAN BURNETT, as Members; GEORGE WILLIAM BEYNON, Stud. Inst. C.E., HENRY RAMSAY COLLINS, JOSEPH HENRY CUNDALL, WILLIAM DEAN, SAMUEL FORBES DOWNING, B.A., JOSEPH HEPWORTH, ARTHUR HILL HOLME, CHARLES WILLIAM JONES, CHARLES HASTINGS MACKIE, Stud. Inst. C.E., PETER ARTHUR MACKINTOSH, THOMAS HENRY MARTIN, WILLIAM MACDONALD MATTHEWS, Stud. Inst. C.E., SAMUEL MOYLE, Stud. Inst. C.E., ARTHUR GRAEME OGILVIE, B.A., HENRY CLEMENTS PERRAM, Stud. Inst. C.E., EDWARD ELLISON PRICHARD, RICHARD MARSHALL ROTHWELL, JAMES MILN SMALL, Stud. Inst. C.E., CHARLES GRAHAM SMITH, Stud. Inst. C.E., and FREDERICK VALENTINE, Stud. Inst. C.E., as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. 7, of the Bye-Laws, had transferred FREDERICK CHARLES BULLMORE and JOHN HEAD from the class of Associate to that of Member.

Also that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-laws, as Students of the Institution:—WILLIAM MEANOR AULD, EUSTACE CROMPTON, JOHN MAUNDER GILL, EDWARD HOMER JEFFREYS, CLAUD SYMS SCOTT, EDWARD MARTIN SMITH, HENRY GRAHAM TAYLER, and SAMUEL ROBERT WILKES, B.A.

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SECT. II.—OTHER SELECTED PAPERS.

No. 1,508.—"Canadian Narrow-gauge Railways." By EDMUND WRAGGE, M. Inst. C.E.

As the narrow-gauge railways constructed into the back country from Toronto have now been in operation for several years, it may not be uninteresting to present the results which have been obtained in working them, in comparison with railways having a gauge of 4 feet 8½ inches and of 5 feet 6 inches passing through somewhat similar country, and having traffic similar in character.

The Toronto, Grey, and Bruce, and the Toronto and Nipissing railways were projected to open up the country, the former in a north-westerly, the latter in a north-easterly direction from Toronto. The Northern railway of Canada, 5 feet 6 inches gauge, occupied the territory between these two railways, and it was felt that unless a railway could be constructed at a much less first cost than had previously been done in Canada, the country could not for some years enjoy railway facilities; hence the determination to construct these railways of a gauge of 3 feet 6 inches.

The Toronto, Grey, and Bruce railway extends from Toronto on Lake Ontario to Owen Sound on the Georgian Bay, a distance of 122 miles, with a branch from Orangeville to Teeswater 69 miles in length, giving a total mileage of 191 miles. It passes over an elevation of 1,462 feet above the level of Lake Ontario, and has ruling gradients of 1 in 60 towards Toronto against the heaviest portion of the traffic, and of 1 in 50 from Toronto, in which direction the traffic is lighter. There is one curve of 462 feet radius, and a few others of 480 and 500 feet radius, having a total length in all of 6,000 feet. The curved portion of the railway is 21½ per cent. of the total length, 78½ per cent. being straight. The extent of level railway is 21 per cent.; with gradients easier than 1 in 100, it is 51 per cent., and with gradients of 1 in 100 and steeper, 28 per cent.

The Toronto and Nipissing railway leads from Toronto on Lake Ontario to Coboconk, a distance of 87 miles, the first 9 miles from Toronto being overcome by means of a third rail laid on the Grand Trunk railway. The summit elevation is 893 feet above

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Lake Ontario, and is reached at a distance of 35 miles from Toronto. The ruling gradients in either direction are similar to those on the Toronto, Grey, and Bruce railway. There are two curves of 600 feet radius (1,650 feet length in all), but no others sharper than 800 feet radius. The curved portion of the railway is represented by 23½ per cent. of its total length from the point at which it diverges from the Grand Trunk railway, and the straight portion by 76½ per cent.; for 19¼ per cent. of the same distance it is level, for 57½ per cent. it has gradients less than 1 in 100, and the remainder, 23¼ per cent., has gradients of 1 in 100 or steeper.

The structures on both railways, station buildings, bridges, culverts, cattle guards, &c., are of timber, and both are fenced throughout their entire length.

The permanent way consists of iron rails weighing 40 lbs. per lineal yard, fished at the joints, and spiked to the sleepers by dog spikes. The sleepers, which are at an average distance of 2 feet 6 inches apart from centre to centre, are 7 feet 6 inches long by 8 inches by 5 inches, and are either of tamarac, hemlock, or black ash. Cedar and rock elm have also been used for renewals, and the new sleepers are 6 inches in thickness, instead of 5 inches as at first. Ballast to a thickness of 12 inches under the sleepers has been used, and the sleepers are well boxed up.

The rolling stock comprises several classes of engines:—1. Engines weighing 16 tons, which have been found too light for the traffic to be accommodated. 2. Engines of 21 tons, having six wheels coupled, which are very useful; those on the Toronto, Grey, and Bruce railway making a daily run of 122 miles, with passenger trains weighing 60 tons, and carrying an average of one hundred passengers. These engines make an average journey of 68 miles while consuming a cord of wood of 128 cubic feet, or 125 miles for 1 ton of 2,000 lbs. of bituminous coal. The schedule time of these trains is 16 miles an hour. 3. Engines of 26 tons, having six wheels coupled, are used for mixed trains on the Toronto, Grey, and Bruce railway, and take a gross load of 180 tons at a schedule time of 14 miles an hour, running 54 miles for a cord of wood. On the Toronto and Nipissing railway they are used entirely for freight purposes, and haul a gross load of 300 tons at an average speed of 10 miles an hour. 4. One Fairlie engine of 42 tons on each railway is found to travel easily on the rails, and is capable of taking considerably heavier loads than the other engines. 5. Engines of 30 tons, with eight wheels coupled, "Consolidation" pattern, are in use only on the Toronto, Grey, and Bruce railway, and haul a gross load of 360 tons up the ruling

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gradients of 1 in 60. Their average journey is 35 miles for a cord of wood.

The passenger carriages were at first 30 feet in length, with an extreme width of 8 feet 6 inches. Those lately put on the railway are 43 feet in length and 8 feet 8 inches in width, and they run more steadily and with greater ease to the passengers.

The wagon stock was in the first instance 15 feet and 18 feet long by 8 feet wide, and upon four wheels, in the English style; but all new stock has been constructed after the American model, and, as well as the passenger carriages, is placed upon four-wheel trucks. All wheels are now 30 inches in diameter, 24-inch wheels having been at first adopted with the view of keeping the centre of gravity as low as possible.

The box cars are 29 feet 1½ inch long by 8 feet wide; they have a carrying capacity in weight, of 24,000 lbs.; in area, of 205 square feet; in bulk, of 1,218 cubic feet; and a dead weight of 15,500 lbs.

The platform cars are 30 feet long by 8 feet wide, having a carrying capacity in weight, of 24,000 lbs.; in area, of 240 square feet; they have frequently been loaded to a height of 6 feet, giving a capacity in bulk, of 1,440 cubic feet; the dead weight averages 13,000 lbs. The floor-level is 3 feet 4 inches above the rail, and the centre of the draw-bar, which is of the common American link and pin pattern, is 2 feet above rail-level.

Owing to the increased weight of rolling stock put on the railways since they were opened, and taking into consideration the increased traffic, the rails now being laid on both railways weigh 56 lbs. to the yard. Already on the Toronto, Grey, and Bruce railway a length of 40 miles at the Toronto end has been laid with the heavier rail, the lighter one having been taken up and used on the branch to Teeswater. These rails are of iron, and on the Toronto and Nipissing railway a length of 7 miles of permanent way has been renewed with steel rails weighing 56 lbs. to the yard.

It may be interesting to remark, in connection with the rolling stock, that two passenger carriages on the Toronto, Grey, and Bruce railway have each travelled upwards of 100,000 miles, the trucks of which have never been repaired since they commenced running; they have the same wheels (chilled cast iron), the same springs, the same brasses, &c.

For the purposes of comparison of traffic and working expenses, the following information respecting the Northern railway and the Midland railway, the former previously referred to, the latter extending from Port Hope to Orillia and Wabushene, and crossing

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the Toronto and Nipissing railway at Woodville, is given. The length of the Northern railway of Canada in the year ending 1875 was 165 miles; the sharpest curve was of 1,432 feet radius; the steepest gradient going north was 1 in 88, going south (towards Toronto) 1 in 100. The summit-level is about 750 feet above Lake Ontario, the weight of rail 56 lbs. per yard. The weight of the engines is from 30 to 35 tons each. The gauge is 5 feet 6 inches. The length of the Midland railway of Canada in the year 1875 was 129 miles. The summit-level is about 700 feet above Lake Ontario; the weight of rail 56 lbs. per yard. The gauge is 4 feet 8½ inches. The stations on the Toronto and Nipissing railway are at an average distance apart of 4·8 miles; on the Midland railway of Canada 5·1 miles; on the Northern railway of Canada 5·4 miles; and on the Toronto, Grey, and Bruce railway 8·7 miles; the latter railway passing through a more thinly settled country than the others, although it is now being fast developed.

The traffic and working expenses of these four railways are shown in the following:—

TABULATED STATEMENT of RECEIPTS and EXPENDITURE on RAILWAYS of 3 FEET 6 INCHES GAUGE COMPARED with RAILWAYS of 5 FEET 6 INCHES and 4 FEET 8½ INCHES GAUGE.

Description.	Toronto, Grey, and Bruce Railway. 3 feet 6 inches.	Toronto and Nipissing Railway. 3 feet 6 inches.	Northern Railway of Canada. 5 feet 6 inches.	Midland Railway of Canada. 4 feet 8½ inches.
	Twelve months ending 30th June, 1876.	Twelve months ending 30th June, 1876.	Twelve months ending 31st December, 1875.	Twelve months ending 31st December, 1875.
Total earnings. . .	$372,336	$207,234	$744,598	$284,322
Total working expenses	$233,428	$120,468	$473,963	$179,221
Percentage of working expenses	62·9	58·1	63·6	63·03
Miles open for traffic .	191	87	165	129
Earnings per mile of railway	$1,949	$2,383	$4,512	$2,204
Total train miles . .	398,681	205,105	641,827	275,560
Earnings per train mile	93·39 cents	100·10 cents	116·01 cents	103·18 cents
Working expenses do..	58·55 „	58·73 „	73·84 „	65·03 „
Net income do. . .	34·84 „	41·37 „	42·17 „	38·15 „
Total car miles . .	2,724,696	1,195,291	4,690,245	1,561,729
Earnings per car mile.	13·66 cents	17·33 cents	15·87 cents	18·20 cents
Working expenses do..	8·56 „	10·08 „	10·15 „	11·48 „
Net income do. . .	5·10 „	7·25 „	5·72 „	6·72 „
Total capital account (including all discounts, &c.) . . .	$4,159,282	$1,600,000	$7,893,569	$4,132,034
Cost per mile of railway	$21,776	$18,390	$47,840	$32,031

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Upon making a comparison of the above figures, it will be found that:—

Broad-gauge railways, average cost per mile = $39,935
" " " net income " = $1,244
Equivalent to 3 per cent. on the cost.

Narrow-gauge railways, average cost per mile = $20,083
" " " net income " = $812
Equivalent to 4 per cent. on the cost.

Working expenses per train mile,					broad-gauge	railway		69·44 cents
"	"	"	"	"	narrow	"	"	58·64 "
"	"	"	car	"	broad	"	"	10·81 "
"	"	"	"	"	narrow	"	"	9·32 "
Net income		"	train	"	broad	"	"	40·16 "
"	"	"	"	"	narrow	"	"	38·10 "
"	"	"	car	"	broad	"	"	6·22 "
"	"	"	"	"	narrow	"	"	6·17 "

These facts, taking into consideration the difference in outlay between the two classes of railways, afford a favourable comparison for the narrow-gauge railways, which pass through a country only lately opened to railway facilities, while the broad-gauge railways have for a great portion of their length been open for many years, the main line of the Northern railway having been in operation upwards of twenty years.

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No. 1,491.—"Experiments and Observations on the Emission of Heat by Hot-Water Pipes." By WILLIAM ANDERSON, M. Inst. C.E.

PROFESSOR BALFOUR STEWART, in his "Elementary Treatise on Heat," articles 229–235 and 285–287, gives a clear explanation of the process of cooling by radiation and convection, and quotes Dulong and Petit's formula, as modified by Hopkins, according to which the total amount of heat radiated per square foot per hour may be found by the expression $m \times a^{\theta}(a^{t} - 1)$, and the heat carried off by convection in atmospheric air by the formula $0{\cdot}0372 \left(\frac{p}{720}\right)^{0{\cdot}45} \times t^{1{\cdot}233}$, in which $a = 1{\cdot}0077$, θ = temperature of air surrounding the pipes, t = difference of temperature between the air and the pipes, both in centigrade degrees, p = height of barometer in millimètres, and m a co-efficient of radiation, which it was the object of the experiments here recorded to determine for hot-water pipes as used in practice.

Reduced to British units and 30 inches of the barometer, the formula becomes

$$\left.\begin{array}{l} u = \text{total units emitted per square foot per hour by radiation and convection . . .} \end{array}\right\} = m \times 1{\cdot}00427^{\theta}(1{\cdot}00427^{t} - 1) + 0{\cdot}2853 \times t^{1{\cdot}233},$$

whence $$m = \frac{u - 0{\cdot}2853 \times t^{1{\cdot}233}}{1{\cdot}00427^{\theta}(1{\cdot}00427^{t} - 1)}.$$

The method adopted for obtaining m was to raise a coil of iron pipes of known weight, and containing a known weight of water, to a certain temperature, then allowing it to cool while observing the temperature at equal intervals of time. Thermometers were inserted into the pipes at the upper and lower ends of the coil, and precautions were taken to guard against accumulations of air in the pipes, and other disturbing causes. The time of cooling and the fall of temperature being thus ascertained, the number of units of heat emitted was easily calculated, and the value of m determined not only for each experiment during the whole process of cooling, but for intervals of about one hour in each case. To make sure that no serious errors of observation had been committed, the fall of temperature was plotted in curves, in which the abscissæ repre-

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sented the time, and the ordinates the temperature of the air as well as that of the pipes. Figs. 1 to 6 (Plate 8) are the curves so obtained. The ordinates of the black curve represent the observed temperature of the top thermometer, those of the curve shown by a fine dotted line the corresponding temperatures of the bottom one; the ordinates of the lower dotted curves represent temperatures of the air. The times from the beginning of the experiment are represented by the abscissæ. The upper set of numbers under the base line give the mean of the two readings represented on the corresponding ordinate, the lower row of numbers the difference between this mean reading and the temperature of the air. In the lower part of the Figs., the ordinates terminated by crosses represent the co-efficient of the coil: thus the ordinate lettered C—D represents the number of units of heat given out by the coil per square foot of surface per 1° Fahr. above the temperature of the air per hour, as calculated between C and D in the upper part of the same Fig. From these figures it will be apparent that a considerable error is committed by assuming, as is commonly done, that the mean temperature of a coil is the arithmetical mean of the extreme temperatures. For example, in Fig. 6, for a coil of 4-inch pipes, the true mean temperature in cooling from 69°·5 down to 23°·7 is 40°·52, while the arithmetic mean is 46°·6. It is obvious, supposing hot water to be flowing through the coil, so as to cool to the same extent during its passage, that the mean temperature would have to be ascertained by a curve in the same way.

Selecting the sixth experiment for illustrating the method of calculation, the process is as follows:—

A weight of 1,564 lbs. of cast iron falling 1° Fahr. in temperature, parts with 1,564 × 0·1138 (specific heat of iron) = ...	178 units
265 lbs. of water falling 1° Fahr.	265 „
Total for 1°	443 „

As there are 87 square feet of heating surface of coil, the total units of heat per square foot dissipated $= \frac{443}{87} \times f = 5{\cdot}092\,f$, where f is the fall of temperature.

Dividing experiments 5 and 6 into four nearly equal intervals, and determining the value of m for each interval, it will be seen from the annexed table that the values agree as closely as may reasonably be expected in, necessarily, somewhat rough experiments. The agreement in the case of the 4-inch pipes is, indeed,

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remarkable; the 2-inch pipes being of much thinner metal, were probably more affected by air currents, and give more irregular results; but even then the first and the third hours and the second and fourth agree very well, the greatest deviation from the mean value of m being only 5½ per cent.

EXPERIMENT No. 5 on a 2-INCH COIL.

Time	1 hour	1 hour	1 hour	¾ hour
t = mean difference of temperature	103°·7	49°·4	25°·4	14°·3
f = fall of temperature	79°·5	35°·5	15°·8	6°·7
θ = mean temperature of air	53°·0	53°·0	52°·5	52°·0
u = total units of heat, per hour	233·73	104·37	46·45	19·7
m = co-efficient of radiation	208·9	234·7	215·8	236·4
Mean value of m =	223·9	..	..	..

EXPERIMENT No. 6 on a 4-INCH COIL.

Time	1·033 h.	1 hour	1 hour	1 hour
t = mean difference of temperature	62°·35	45°·83	33°·94	27°·31
f = fall of temperature	18°·5	13°·0	9°·2	7°·1
θ = mean temperature of air	60°·0	60°·0	60°·0	59°·0
u = total units of heat, per hour	94·20	66·20	46·85	36·15
m = co-efficient of radiation	120·3	122·52	122·93	120·98
Mean value of m =	121·68	..	..	..

The results of the eight experiments are recorded in the following tables (see next page).

The seventh column gives the mean value of m in each case, and the eighth column the calculated number of units, from such mean values of m, of heat emitted per hour from 1 square foot of surface with the atmosphere at 60° and the mean temperature of the coils at 110°, being a difference of 50°.

The 2-inch coils forming the subject of the first five experiments were made of common 2-inch galvanised pipe, connected together by galvanised wrought-iron elbows, as represented in Fig. 7. The coils were not covered by a casing, and were placed in a boiler-house tolerably well protected from draughts.

Experiments 2 and 4 were designed to ascertain if placing a vertical sheet of iron between the two rows of pipes would have any effect on the rate of cooling, by preventing one set of pipes radiating against the other, and making them radiate against a plate, which would part with its heat by convection to the current of air passing up between the row of pipes. The effect has been apparently to reduce the cooling power of the pipes.

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VALUES of the CO-EFFICIENT m of RADIATION in the FORMULA $u = m \times 1{\cdot}00427^{\theta} (1{\cdot}00427^{t} - 1) + 0{,}285 \times t^{1{\cdot}233}$ DERIVED from EXPERIMENT.

—	1 Duration of Experiment.	2 Maximum Temperature of Coil.	3 Mean Temperature of Air = θ.	4 Mean Temperature of Coil.	5 Mean Difference of Temperature between Coil and Air = t.	6 Fall of Temperature during Experiment.	7 Mean value of Co-efficient of Radiation = m.	8 Units of Heat per Square Foot for 50° Difference, 60° Air. Calculated from Co-efficient.
	Hours.	°	°	°	°	°		
Experiment No. 1 (Fig. 1).—A single coil of 2-inch galvanised iron pipes; heating surface 25·949 square feet. Weight of galvanised wrought iron in coil, 205 lbs.; weight of water contained in coil, 53 lbs. . . .	3·5	206·0	51·5	103·0	51·5	143·0	270·9	119·1
Experiment No. 2 (Fig. 2).—A single coil same as No. 1, but with a vertical sheet of iron between the coils	3·833	205·0	50·13	100·28	50·15	144·5	252·9	113·5
Experiment No. 3 (Fig. 3).—A single coil same as No. 1, but blackleaded	3·833	206·0	52·9	103·75	50·85	143·3	241·0	109·9
Experiment No. 4 (Fig. 4).—A single coil like No. 2, with vertical sheet between coils, and blackleaded	3·583	205·09	52·27	106·07	53·8	140·5	235·3	108·1
Experiment No. 5 (Fig. 5).—A single coil same as No. 1, but with a second similar coil placed next to it	3·833	202·0	52·62	103·66	51·04	138·0	231·8	107·2
Experiment No. 6 (Fig. 6).—A coil of 4-inch cast-iron pipes; 87 square feet surface. Weight of cast iron, 1,564 lbs.; weight of water contained, 265 lbs. .	4·033	133·0	59·75	102·11	42·36	47·8	121·7	73·0
Experiment No. 7.—Coil of 2-inch cast-iron pipe in room of office at the Erith Ironworks, blackleaded, uncased; 34·2 square feet heating surface. Cast iron, 318 lbs. weight; water, 64 lbs. weight	3·0	130·5	61·5	98·5	37·0	53·2	123·03	73·44
Experiment No. 8.—The same as No. 7	4·0	133·5	61·4	95·8	34·45	61·7	108·8	69·0
Experiments Nos. 9 and 10.—Battery of 2-inch wrought-iron tubes, connecting two cast-iron steam chests heated by 36 lbs. steam; 232 square feet of surface	1·0	282·0	58·71	282·0	223·3	..	272·3	..
	1·0	282·5	59·5	282·5	223·0	..	262·9	..

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In experiments 3 and 4 the pipes were washed over with black-lead, and brushed, the effect being again to reduce the rate of cooling, though to a very small extent.

Experiment 5 was designed to ascertain whether a second coil placed beside the first would affect the rate of cooling by preventing radiation on one side. The loss of power was, however, only 10 per cent.

The experiments on the 2-inch coils were made in the order in which they stand recorded in the table. It is not improbable that the gradual decline in the rate of cooling may have been due to a slight accumulation of deposit from the water used.

There is a striking difference in the rate of cooling between the 2-inch wrought-iron and the 4-inch and 2-inch cast-iron pipes, the latter yielding only 66 per cent. of the heat given out by the former. It is not easy to explain this fact, because there is so little difference between the amount of heat emitted by the 2-inch and 4-inch cast-iron pipes. The difference in the thickness of metal between the 2-inch wrought-iron and 4-inch cast-iron pipes will be as $\frac{3}{16}$ inch to $\frac{7}{16}$ inch, but the 2-inch cast-iron pipes are not more than $\frac{1}{4}$ inch thick. Therefore, if the thickness of metal is the cause, the small cast-iron pipes ought to cool much faster than the large ones, yet the experiments show that they do not. The 2-inch cast-iron pipes, however, have been in use for several years, and although the water in them has been rarely changed, there may be some deposit on their inner surfaces. The 4-inch and 2-inch wrought-iron pipes were new, and put together expressly for the experiments.

An examination of the formula shows that radiation only is affected by the temperature of the atmosphere, and that the emission of heat is greater as the temperature of the air increases. Taking the case of the 4-inch cast-iron pipes, with $m = 122$, a constant difference of temperature, $t = 50°$, the total heat emitted per square foot per hour becomes $u = 29{\cdot}13 \times 1{\cdot}00427^{\theta} + 35{\cdot}46$, and solving for θ, the temperature of the atmosphere ranging from 32° to 60°, the following result is obtained:—

Temperature of air, θ =	32°	39°	46°	53°	60°
Total heat units, u =	68·87	69·89	70·94	72·01	73·13

The difference of emission between the extremes is only 4·26 units, or a little over 6 per cent. more at 60° than at 32°. As for the purpose of warming buildings the air in the rooms is generally taken to be at 60°, and as any small variation from that temperature will not affect the rate of cooling much, two curves may be

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calculated for 4-inch cast-iron and 2-inch wrought-iron pipes, with the co-efficient of radiation 122 and 250 respectively (the mean of the several values of m), which will enable the total units of heat given out per square foot of surface per hour to be ascertained by inspection for any difference of temperature. Fig. 9 gives these curves. Suppose, for example, it is required to know how much heat will be given out by 4-inch pipes at 190° in a room, the temperature of which is 60°, the difference of temperature being 130°: look along the line of abscissæ for 130, and the ordinate then gives 232·7 units for 4-inch pipes, and 356 units for 2-inch wrought-iron pipes per square foot per hour.

The heating surface necessary to warm a given building depends on a variety of circumstances—on geographical position, whether the house stands high and exposed or low and sheltered, and whether the average winter temperature is high or low; on the thickness and material of walls; on the area and construction of windows, and so forth. Very little can be done by calculation; the area as well as disposition of the pipes must be a matter of judgment. It is a great help, however, to know what has been done in other buildings. The annexed table (see p. 264) has therefore been compiled, from which it would appear that for ordinary dwelling-houses 1 square foot of surface is necessary to every 65 cubic feet of air to be heated, and in a greenhouse 1 square foot to every 24 cubic feet of air.

When the water circulates through the pipes by virtue of the difference of temperature of the flow and return currents only, it is impossible to count upon a greater mean temperature of the pipes than from 160° to 180°, because above that temperature the water in the boiler begins to boil, and causes an overflow of the supply cistern and escape of steam at the air pipes. Where forced circulation is adopted, as, for example, at the Third Middlesex County Lunatic Asylum, at Banstead, near Sutton, where the water is propelled by a centrifugal pump, and where it is under a pressure of about 70 feet, a much higher temperature can be attained. One of the advantages in heating by steam is the high temperature that can be obtained in the pipes, but the disadvantage is that it is difficult to moderate the temperature in warm weather. The case of the pattern shop given in the table is anomalous, and no certain deductions can be made from it, because of the exceptional circumstances mentioned. The Author at one time thought that pipes heated by steam might possibly emit heat quicker than those warmed by hot water. Some experiments, however, made in 1870, on a tubular steam heater, have shown that the rate of emission was

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as nearly as possible the same as with tubes of the same size heated by water. The heater consisted of fifty-nine 2-inch wrought-iron tubes 6 feet 5 inches long, connecting two cast-iron steam chests 7 feet long and 1 foot 3 inches wide. By means of diaphragms in the chests, the steam was made to circulate through the pipes. The heating surface of the tubes was 197 square feet, and of the steam chest 35 square feet, or 232 square feet in all. Two experiments of an hour's duration each were made to ascertain the weight of steam that would be condensed. The result was that 184½ and 180 lbs. of water were drawn off in the two experiments. From this it is easy to calculate that 785·7 and 766·5 units of heat per square foot per hour must have been given off, and that the co-efficient of radiation must have been equal to 272·3 and 262·9, or nearly the same as that derived from the 2-inch wrought-iron water pipes.

The experiments on the heating powers of the hot-water pipes were conducted by Mr. Bonham Carter, to whose care and accuracy the Author is much indebted.

The communication is accompanied by sketches, from which Plate 8 has been compiled.

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APPENDIX.—EXAMPLES of BUILDINGS and

Description of Building or Room.	Approximate Working Temperature of Pipes.	Cubic Feet of Air contained.
	°	
Lesney House, Erith, Kent.		
The whole house is warmed by hot water, more especially the passages, which in the coldest weather can be maintained at 60°. The rooms all open into the passages. The house stands 150 feet above the river, and is much exposed :—		
Study.—Bow window to the east. Hot-water pipes under window seats, with three openings 7 inches by 4½ inches, covered by perforated zinc, through the walls to admit external air through coils. Coils concealed by open cast-iron work; constant current up the chimney. Only one external wall, namely, the bow window	160	3,329
Dining Room.—Bow window facing to the north, with coils in all respects as in the study. Another window faces to the west. Two external walls	,,	5,386
Bath Room.—One window, facing west; group of pipes placed against inner wall opposite window; no communication with external air; open chimney. One external wall	,,	1,072
Erith Public Elementary Schools.		
One-story brick buildings, not plastered inside, stand near the river, and sheltered by surrounding houses, the roofs ceiled up to the collar tie. The coils of pipes are quite open, and placed near the walls, most of which are external :—		
Boys' school	,,	24,917
Girls' ,, ...	,,	26,257
Infants' ,, . Total	,,	37,195
Class rooms.—A.	,,	5,206
,, B.	,,	4,932
,, Babies'; south aspect	,,	6,544
Offices of the Erith Ironworks.		
Two-storied brick building, plastered inside, standing near the river, but well sheltered, nearly all the walls external, no fireplaces, but ventilating pipes to carry off foul air, and flues in walls to bring fresh air to coils, all of which are uncovered and placed, with one exception, against inside walls	,,	30,597
Ground Floor of Pattern Shop, Erith Ironworks.		
Heated by a waste steam pipe, running round the room near the floor, for the most part under the benches. An 8-HP. steam engine works in the room. Well sheltered, thick walls, iron sashes; a great deal of gas burned morning and evening .	217	80,698
Greenhouse at Lesney House.		
The north-east wall is protected by a potting shed, and one end abuts against a hothouse of similar construction	160	3,184

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ROOMS WARMED by HOT-WATER PIPES.

External Cubic Capacity.	Area of Heating Surface.	Cubic Feet to 1 Square Foot of Heating Surface.		Cubic Feet of Air to 1 Square Foot of Heating Surface reduced to 160°.	Area of Walls and Ceilings.	Number of Square Feet of Wall Surface to 1 Square Foot of Heating.	Area of Windows.	Remarks.
		Air.	Total External Capacity.					
	Sq. feet.				Sq. feet.		Sq. feet.	
..	83·0	40·0	..	40·0	1,098	13·2	96	Excess of heating power.
..	83·0	65·0	..	65·0	1,481	17·8	118	Sufficient heating power.
..	53·3	20·1	..	20·1	525	9·9	18	Great excess of heating power.
29,465	326·0	76·4	90·4	76·0	5,213	16·0	342	Only just heating surface enough.
32,890	325·0	80·8	101·5	80·8	4,409	13·6	342	Hardly sufficient heating power.
41,350	442·0	84·1	93·8	84·1	5,198	11·7		Insufficiently heated.
..	51·0	102·0	..	102·0	830	16·2	432	These rooms are too cold for the comfort of the children.
..	50·0	98·6	..	98·6	830	16·6		
..	83·0	78·8	..	78·8	1,230	14·8		Barely sufficiently heated.
44,217	472·0	64·8	93·8	64·8	640	13·6	..	Sufficient heating power.
87,492	360·0	224·0	243·0	126·0	10,493	29·0	..	Sufficiently heated.
..	132·0	24·1	..	24·1	1,156	8·8	586	Sufficient to maintain 60° in coldest weather.

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MEMOIRS OF DECEASED MEMBERS.

MR. OSBORNE CADWALLADER EDWARDS, son of Anthony Edwards, of Hop Island, Cork, one of the original proprietors of the "Cork Constitution" newspaper, was born in the year 1822. He was trained to the engineering profession by the late Mr. Richard Beamish, M. Inst. C.E., under whom he was engaged as Assistant-Engineer from 1845 to 1850, chiefly upon the Gloucester and Dean Forest and South Wales railway, and on the resignation of Mr. Beamish was engaged directly under the late Mr. I. K. Brunel, V.P. Inst. C.E., as Resident Engineer for that line. In 1852 he was selected by Mr. Brunel to take charge of the Oxford and Birmingham railway, and in 1854 was transferred to the Cork and Youghal railway, of which he became Engineer-in-Chief in 1859, on the death of Mr. Brunel, and was retained as Consulting Engineer on its completion. For some time, too, he was occupied upon the Fermoy and Lismore railway, for the Duke of Devonshire; and for several years was Engineer to Beamish and Crawford's brewery. Mr. Edwards was a warm supporter of the Irish Church, and, after its disestablishment, never charged any fees for professional work in connection with it. He was an ardent and zealous Freemason, and at the time of his death was the Provincial Grand Secretary of the Masonic province of Munster. Mr. Edwards was elected a Member of the Institution on the 4th of April, 1865, and died on the 5th of June, 1876, greatly respected and esteemed.

MR. CHRISTOPHER BAGOT LANE was born in 1814 at Nurney House, Co. Kildare, Ireland, the residence of his grandfather, Mr. Christopher Bagot. After studying at Trinity College, he graduated at the Dublin University. His father, a surgeon in the army, desired that he should follow the medical profession, and to that end placed him with the late Sir Philip Crampton, Bart. Civil engineering proving, however, more attractive than medicine, Mr. Lane, after the lapse of about a year, left Dublin for Edinburgh, where he speedily fitted himself for the duties of his new profession under University and other professors, and as a pupil of

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Mr. Ruthven, architect. Between 1835 and 1837 he was employed on the Trigonometrical Survey of Ireland under Colonel Colby, R.E., on extensive surveys along the west coast. In December 1837 he was admitted into the London office of the late Mr. I. K. Brunel, V.P. Inst. C.E., who was then constructing the Great Western railway, and with whom he remained for some years, being successively employed as an assistant-engineer under Mr. R. B. Grantham, M. Inst. C.E., and Mr. G. T. Clarke, on portions of the Great Western railway; from 1840 to 1842 in laying out railways at Merthyr Tydvil and Dowlais, as extensions of the Taff Vale railway; in 1843 and 1844 on the construction of the Bristol section of the Bristol and Gloucester railway, both for the broad and narrow gauges, under Mr. J. W. Hamond; in 1845 in preparing the parliamentary plans and sections for the South Wales railway, and with Mr. R. Brodie in getting out the estimates for that line; and from 1846 to 1849 as Resident Engineer of the Extension of the Birmingham and Oxford Junction railway through the town of Birmingham, having previously taken part in the preparation of the designs and estimates for the line. In 1846 he was appointed Professor of Civil Engineering at Trinity College, Dublin, which, however, his more active duties obliged him to resign. In 1849 he was nominated by the Lord Lieutenant of Ireland as first occupant of the chair of Civil Engineering at Queen's College, Cork, which office he held with marked success till 1853.

At about this period railways were beginning to be introduced into Brazil, and the Imperial Government sought in England the services of some engineer of large experience and high character who might be constantly at hand to advise them in such matters. Mr. Brunel was requested to recommend some gentleman possessing these qualifications. He named Mr. Lane as eminently fitted for the post, who thereupon accepted the offer, relinquishing his professorship at Cork. In July 1853 he took up his residence at Rio de Janeiro, as Consulting Engineer for Railways to the Brazilian Government. In this capacity he remained for six years, during which period three trunk lines were carried out, chiefly by English companies. He was constantly referred to by the Government, not only on points of construction, but also on matters of railway legislation, management, and finance. In 1860 Mr. Lane returned to England, but the Brazilian Government, appreciating the value of his services, continued his engagement for more than eighteen months in London.

From 1864 to 1872 he was associated with Mr. E. Bagot, Assoc.

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Inst. C.E., as joint Engineers for the construction of the Swansea and Carmarthen extensions of the Llanelly Railway Company, and in connection with that company they prepared plans for various lines in South Wales and for docks at Llanelly, and also for the branch railway and docks at the Mumbles, near Swansea. During the last few years of his life Mr. Lane made four journeys to South America, chiefly for the purpose of examining and reporting upon railways, projected or in course of construction, or of settling difficulties that had arisen between the parties concerned in them; his long professional experience, his knowledge of the country, language, and people, and his perspicacity and sound judgment rendering him particularly well adapted for such missions.

Mr. Lane was elected an Associate of the Institution on the 6th of March, 1849, and he was transferred to the class of Members on the 2nd of December, 1856. In 1851 he communicated a Paper on the Birmingham Extension of the Birmingham and Oxford railway,[1] for which a Council premium was awarded; and later, on his return from Brazil, he constantly attended the meetings, and frequently took part in the discussions. In January and April 1852, he contributed two Papers to the Institution of Civil Engineers of Ireland;[2] the first, describing the works of the North Holland railway, concluding with observations on single and double lines, with special reference to the development of railways in Ireland; the second entitled "Observations on Earthworks," which set forth clearly the amount and distribution of the labouring force required in large cuttings and embankments. In 1860, when the subject of metropolitan intercommunication was receiving much attention, Mr. Lane published a pamphlet entitled "Railway Communication in London, and the Thames Embankment," in which he advocated the construction of a high-level railway extending from the Minories to Kensington, and following the line of the Thames Embankment, his object being to link together all the London termini of the leading lines, which was in part provided for by the Metropolitan railway. In this year he took the degree of LL.D. at the University of Dublin.

Mr. Lane was particularly fond of mathematical science, which remained throughout life a favourite pursuit. Possessed of a cultivated intellect, and a mind of considerable grasp, he had wide

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xi., p. 69.

[2] *Vide* Transactions of the Institution of the Civil Engineers of Ireland, vol. iv., part iii., pp. 12 and 64.

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information, which a retiring disposition prevented from being generally known and appreciated; and he had also excellent business powers. His sympathies with and influence over young men were invaluable, always inspiring them with high and noble motives; while all who knew him will remember him as a genial companion, a warm and generous friend, a man of the most unselfish disposition, and one actuated by the highest principles of honour and integrity. He died on the 11th of January, 1877.

MR. THOMAS TALBOT BURY[1] sprang from a Worcestershire family, his mother having been a descendant of the Earls of Shrewsbury. He was born on the 26th of September, 1811. In 1824 he was articled to Mr. Augustus Pugin, architect. Amongst his fellow-pupils were Ferrey, Dollman, Shaw, Lake Price, Nash, Walker, and Charles Mathews; of the thirty-four or thirty-five pupils who were at one time or other in Mr. Pugin's office, only Mr. Bury, Mr. Ferrey, Mr. Dollman, Mr. Walker, and Mr. Green actually followed the profession of architecture. In 1830 Mr. Bury commenced to practise on his own account. In 1847 he wrote, and illustrated with his own hand, "The Remains of Ecclesiastical Woodwork," and this was followed in 1849 by a "History and Description of the Styles of Architecture of Various Countries from the Earliest to the Present Period." These works were published by Weale, and show an accurate and extensive knowledge of the subjects treated of. Mr. Bury co-operated with Welby Pugin in working out the designs and details of the Houses of Parliament for the late Sir Charles Barry, and when the younger Pugin claimed for his father the sole merit of this work, Mr. Bury indignantly denied the justice of such a claim, and did full honour to his employer. He either built or took part in the restoration of seventy-four churches during his professional career. He at one time assisted the late Mr. Lewis Vulliamy in some important works, and was in partnership for about four years with Mr. Charles Lee. Mr. Bury was a great collector of architectural and antiquarian books, and of water-colour drawings, the former consisting of rare works and good editions. His collection of ancient

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[1] This memoir has been compiled from a notice by Mr. T. H. Wyatt, in the Transactions of the Royal Institute of British Architects.—SEC. INST. C.E.

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carved cabinets and of panels illustrating the history of wood carving was probably unique. His water-colour drawings show his power as an artist, and he was a frequent exhibitor at the Royal Academy. He was hardly less apt as an engraver, many of the most beautiful plates in Owen Jones's work on the "Alhambra" having been engraved by him; and as a lithographer he was skilful and refined.

It may be stated that Mr. Bury employed iron with great success in the structures which he designed, and he exhibited considerable ability in adapting the proper proportions of metal whilst giving to the parts graceful forms. He was elected an Associate of the Institution of Civil Engineers on the 2nd of May, 1848, and was a fellow of the Society of Antiquaries and of other kindred societies.

For the last two or three years of his life he was a sad invalid, suffering severely; but latterly he rallied a good deal and was able occasionally to attend the meetings of the Royal Institute of British Architects; and, as one of its Vice-Presidents, took a considerable share in important recent deliberations of the Council. The recovery of his health was not of long duration, and his end was very rapid. He died on the 23rd of February, 1877.

Mr. ROBERT WOOD EVERETT GREEN was born on the 29th of January, 1847. He was educated first at a private school, and afterwards at King's College, London, taking at both places a position in advance of his age. After a year spent with a private tutor, in 1863 he entered the Science Department of King's College, devoting himself especially to engineering. In 1864 he was articled to Mr. F. W. Sheilds, M. Inst. C.E., with whom he remained two years. He then entered the ironworks of the Teviotdale Company, near Dudley, and after some months, was commissioned to superintend the erection of iron gates in the dock constructed for the Messrs. Brogden, at Porthcawl, South Wales. His professional studies were completed in 1867, and he became a candidate for a position in the Public Works Department of the Government of India, and after preliminary study, under Mr. C. P. Shelley, Assoc. Inst. C.E., he passed first in the examination of December of that year.

On the 4th of February, 1868, he sailed for Calcutta; and having selected the Punjab as his field of action, was stationed at Pind Dadan Khan, to take the post of an absent senior, and,

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proving himself adequate to the position, was retained in it. Whilst there, he had charge of a considerable district, including the important salt-mines of Kheora, from which Government derived a large revenue, and where he drove several new drifts. On one occasion of sudden flood, the water broke down a wall, threatening to make its way into the mine, and endangering its safety, the pillars being all of salt. Mr. Green, then young on the station, telegraphed to head-quarters for orders. The reply was: "You are on the spot: you must do what you think best. You may press men." Several hundred men were pressed, and worked in gangs night and day, he himself never leaving the mine. A protecting wall was built only just in time. A tempest came on violently a few hours afterwards, but the wall stood, except a small portion where the mortar was still wet, and the mine was saved. His other chief works there were the construction of a bridge of boats across the Jhelum, the sinking of wells, repairing roads, church, and cemetery, and building a hospital at Talagung, &c.

Early in 1870, he was transfered to the irrigation works, and was stationed on the Baree Doab canal, his head-quarters being at Punjgriani, 8 miles from Umritsur. Here he had 50 miles of canal to survey, and at first the work went on prosperously, but it became tedious in time, from the difficulty of obtaining the necessary government orders for the masonry required.

After six months' furlough, in September 1873 he was sent to take temporary charge of famine relief works, first on stations south of the Ganges, in the Patna and Dinapore districts, and later, north of the Ganges, at Bettiah, near Moteharee. His assiduous labours elicited special notice in the Indian press, and procured for him the thanks of Government. But his health gave way, and in April 1875 he came home on furlough for nine months. He improved considerably while in England, and returned to his duties in December 1875. He was then stationed on the Sirhind canal, at Bool, near Loodianah, having about 30 miles of the canal under his care. In April 1876 he had an attack of dysentery, which shook him a good deal, and left his health in a delicate state, from which he never recovered. He died on the 12th of September, 1876. A few days later, his promotion to the rank of Executive Engineer would have been gazetted.

He was a young man of warm domestic affections and generous impulses, with a high sense of honour, and of considerable ability and cultivated taste. He was noticed in India as one of the few men who carried the amenities of civilised life into the jungle.

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He contributed occasionally to periodical literature, both in England and in India, but not on scientific subjects.

Mr. Everett Green was elected an Associate of the Institution of Civil Engineers on the 7th of March, 1876.

Mr. THOMAS TENISON RYAN was born on the 17th of June, 1835. At the age of seventeen he was articled to the late Mr. T. J. Woodhouse, M. Inst. C.E., being employed from the autumn of 1852 until 1856 on the studies and construction of the Turin and Novara railway, and subsequently upon the Chivasso and Ivrea railway, the Mont Cenis tramways and docks at Genoa, all of which were being carried out by Mr. Woodhouse, and on his death by Mr. Charles Henfrey, for the late Mr. Brassey, Assoc. Inst. C.E. Here Mr. Ryan gave great satisfaction, and on the completion of his articles was recommended by Mr. Henfrey to Mr. John Watson, M. Inst. C.E., for whom, in October 1858, he went to Brazil as an assistant on the contractor's staff of the Bahia and San Francisco railway, his position being that of a District Engineer. After remaining five years in Brazil Mr. Ryan returned home, and until March, 1866, acted as Mr. Watson's agent on the Mid-Wales railway, having charge, latterly, of the entire line, including junctions, &c. On leaving Mr. Watson he received a flattering letter commending his ability, zeal, and steadiness. Mr. Ryan was by this time thoroughly conversant with the construction of railway works, to which branch of the profession he had always given the preference, and though the commercial crisis of 1866 had to a great extent paralysed engineering at home, he procured an appointment as agent and Engineer for Messrs. Eckersley and Bayliss, the contractors for the Bath and Mangotsfield branch of the Midland railway. Here he remained until October 1868, when, having passed the prescribed examination, he entered the service of the Government of India, under a covenant for five years, as an Executive Engineer in the Department of Public Works. He was at first put in charge of 50 miles of the Banda and Saugor road and of the northern division of the Agra Grand Trunk road, but in March 1870 was transferred to the railway branch, and employed on the studies and construction of the Kharrian Pass, Punjab Northern State railway; afterwards he took charge of the Khanpur division of the Indus Valley line. While thus occupied, Mr. Ryan became seriously affected by malaria and jungle fever, and though specially recommended for promotion, he was obliged to leave India

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at the termination of his five years' agreement. After in some measure recruiting his impaired health, Mr. Ryan was for a few months again employed by Mr. Watson on surveys for an extension of the Mid-Wales railway, and subsequently received an appointment in the Public Works Department of the Cape of Good Hope, arriving in Cape Town on the 11th of April, 1875, and being employed under the Chief Inspector of Public Works, principally in the construction of roads. But the trying climate of the Indus Valley had completely undermined his constitution, and after a short service in the department Mr. Ryan died on the 16th of December, 1876. He was elected an Associate of the Institution on the 5th of December, 1871.

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SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

On the Construction and Working of the St. Gothard Railway.[1]

By G. PACHO.

(Il Politecnico, vol. xxiv., p. 565.)

The execution of the St. Gothard railway, the design of which was to place Italy in direct communication with eastern Switzerland and with western Germany, is opposed by serious difficulties. A loss of at least £4,000,000 sterling is threatened, according to the calculations of the last-appointed Engineer, M. Hellwag. The operations have been suspended, the staff discharged, and only the works of the great tunnel are being carried on. From the report of the directors of the company it is possible to form an idea of the cause of the mischief.

After a long contest between the promoters of the three Alpine lines of St. Gothard, Lucomagno, and the Splügen, the St. Gothard valley was finally selected as the line which appeared to promise most advantage at the least cost.

By an agreement dated the 28th of October, 1871, the delegates of Switzerland, Italy, the North German Confederation, Würtemberg, and the Grand Duchy of Baden, united their efforts to overcome, by means of a Swiss railway through the St. Gothard pass, the obstacle, presented by the Alps, to the junction of the railways of Central Europe with those of the Italian peninsula.

After an examination and survey, the details of which occupy two volumes published by the Italian ministry, it was estimated that the total cost of the undertaking, including the approaches, the tunnel, and the complementary lines, would amount to £7,480,000. In order to attract private enterprise to the work it was considered necessary that the sum of £3,000,000 should be subscribed by the states interested in the communication, as an absolute gift, in which case it was anticipated that the remaining £4,480,000 might be obtained by subscription. The estimated revenue was given at £252,480 per annum. It appears, however, that the preliminary surveys were far from accurate. The International Commission contented themselves with prescribing that the works should be executed with the utmost economy.

[1] *Vide* also Minutes of Proceedings Inst. C.E., vol. xlii., p. 228.

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The St. Gothard Railway Company was formed on the above basis. The capital was subscribed. A contract was entered into with M. Favre, the contractor for the Mont Cenis tunnel, to execute the tunnel under St. Gothard, and the work was commenced. The network of railway which it was intended to construct amounted to a total length of 164 miles. Soon afterwards, however, important deficiencies were remarked in the estimates. In April 1874 the Chief Engineer Gerwig presented a further detailed estimate of the cost of construction, which exceeded by about £1,168,000 his estimate of 1872. M. Gerwig resigning his post, was succeeded by M. Hellwag, who considerably modified the plans of his predecessor, and arrived at an estimate exceeding that of the International Commission by £2,412,440, making the total cost of the line amount to £9,892,440. The chief difference in these estimates arose in the approaches to the tunnel. M. Hellwag's plan was based on the principle of keeping the line near to the bottom of the valleys, so as to maintain communication, at the stations, with the existing roads, and then to ascend the scarp of the mountains, at the entrance of the tunnel, by a series of zigzags, or as he called them "helicoid volutes," constructed at the most appropriate points. It was expected that this method would prove the cheapest. The result of the detailed plans was, however, this increase of £2,412,440 on the former estimate.

Without entering into the details of this considerable difference, the Author proceeds to point out that the cost of the two lines in the valley of the Ticino, now open, namely the Biasca-Bellinzona-Locarno,[1] and the Lugano-Chiasso[1] sections, which had been estimated by the International Commission at £742,400, amounted, or would amount when complete (after allowing for a loss on working in the first instance, before the completion of the entire line), to £2,064,000; a difference which, in the opinion of the members of the General Committee of Direction of the St. Gothard line, is "truly colossal."

The reasons for this extraordinary excess, according to Signor Pacho, become apparent on a perusal of the report of M. Hellwag; who is accused of having entirely lost sight of the real object of the railway, that is to say, the formation of a route for transit from Italy to Germany. To give an idea of the scale of magnificence adopted, it is mentioned that the provision of sidings and accessory lines on this section, which had been calculated by the International Commission at 20 per cent. of the length of the mileage, amounts, according to M. Hellwag's plan, to a length equal to that of the total mileage of the section. This explains how an estimate of £742,000 has been swollen to one of £2,064,000.

The report of the directors, drawn up under these circumstances, remits to the Federal Council of Switzerland the task of entering into fresh arrangements with the other interested states, for the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xl., p. 277.

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purpose of raising the additional funds now found to be necessary for the completion of the line. To meet the responsibility of the directors, it is calculated that at least the original subscription, or free gift, of £3,000,000 must be increased by the further sum of £4,094,840, a demand which appears to the directors difficult to urge.

To give an idea of the differences shown by the revision of the estimates, the following particulars are cited. The estimate of the International Commission for the cost of the general administration, comprising the expenditure incurred in raising the capital, and the expenses of the central administration, was £74,156. That of M. Hellwag, in 1876, amounted to £258,880. The cost of surveys, in the former estimate, was set down at £100 per mile, amounting to £26,540. In the latter it stands at £268 per mile, giving an amount of £71,200. For purchase of land the first estimate allowed £179,760; the second, £456,960. For the station at Lucerne, and the fourteen sections of line on the Swiss side of the Alps, the estimate of the Commission was £3,840,404; that of M. Hellwag £6,795,124. For the tunnel itself the additional cost was only 2½ per cent. For the three sections of line on the Italian side, 178 per cent. was added to the former estimate. The general account of cost, according to M. Hellwag, was as follows:—

	£.
Reimbursement of preliminary expenses	20,200
Raising capital	244,800
General administration	138,472
Interest to opening of line	1,309,800
Engineering (technical direction)	459,968
Actual construction	9,401,620
	11,574,860
Estimate published by Italian Government . . .	7,480,000
Deficit	4,094,860

To this sum, however, a considerable addition has to be made for interest during the time occupied by the suspension of the works. As the total length of line composing the entire network was 164 miles, this gives a cost of £70,578 per mile, whereas the original estimate was £45,610 per mile.[1]

[1] The actual length of the St. Gothard Tunnel, which is not given in Signor Pacho's Paper, is 16,241 yards. The work was contracted for by M. Favre, on 7th August, 1872, at a price equivalent to £116 8*s.* per yard, to be completed in eight years. *Vide* Minutes of Proceedings Inst. C.E., vol. xlii., p. 228.

The last 4,781 yards of the Mont Cenis Tunnel were let to MM. Sommeiller and Grattoni at a price equivalent to £167 12*s.* per lineal yard. It was conjectured that the cost to the contractors did not exceed £74 per lineal yard. The preliminary estimate of the total cost of constructing the Mont Cenis Tunnel amounted to £2,600,000; which was at the rate of £194 per lineal yard. It is supposed that the actual cost amounted to £3,000,000, which is equivalent to £224 per yard; or £394,240 per mile. The cost of the Thames Tunnel was £1,137 per lineal yard. *Vide* "Practical Tunnelling," by F. W. Simms, C.E. Third edition, revised by D. K. Clark, M. Inst. C.E.—F. R. C.

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Starting from the above data, and considering that the deficit of £4,094,860 could not well be covered by the issue of shares or debentures at less than 6 per cent., and that any addition either to the capital raised, on the one hand, or to the time consumed by suspension of works on the other, must add to the final cost of the undertaking, there seems every reason, the Author thinks, to anticipate that, without the aid of a considerable subsidy from the states interested, the deficit will amount to at least £4,400,000. It is possible that the original estimate was too low. But it was based on the experience previously obtained in the execution of Alpine lines, the prices of which had been adopted by the Commission as normal.

The remainder of the Paper is taken up with a detailed examination of the economies which might be effected in the execution of the works; and by the substitution of steamers on the Lake of Lucerne for the construction of certain portions of the line. The gradients vary from 1 in 122 to a maximum of 1 in 26·77, the mean ascent from the station of Silencia, on the northern side, to that of Göschenen. On the Italian side the mean gradient is 1 in 28·65.

F. R. C.

Works undertaken for the Consolidation of the Bed of the Calabrian Railway, near Torre Vecchia.[1] By S. Bilia.

(Giornale del Genio civile, vol. xiv., p. 41.)

The railway from Taranto to Reggio, on leaving the dunes, which it crosses between the station of Crucioli and a point about 1 mile beyond the torrent Gianturco, runs for a similar distance through a zone of slippery ground, from 50 to 100 yards wide, lying between the sea and the face of an ancient shore line of much higher elevation. The space in question presents all the features of recent disturbance. The surface is irregular, with numerous clefts, marshy spots, deep depressions, and swelling hills. It is nearly devoid of vegetation. The passage of the spot, which presents the aspect of a yet unsettled landslip, could only be avoided by running along the sandy margin of the sea (which would have involved the construction of costly sea walls); or by means of a tunnel of 1,400 or 1,500 yards in length (which would not only have been costly, but would have had to pass through a portion of the slippery ground); or by ascending the landward cliffs, which would have involved the adoption of gradients of from 1 in 83 to 1 in 67, while the ruling gradient of the line is only 1 in 200. It thus became necessary to study the means by

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlvii., p. 328.

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which the dangerous soil in question could be consolidated so as to support the permanent way.

The Sub-Apennine hills, which occupy the greater portion of the coast of the Ionian sea in the province of Calabria, in some places closely approach the shore, and in others recede to a considerable distance; the interval being occupied by a zone of diluvial soil which has been brought down by numerous torrents. The Point of Torre Vecchia advances boldly from the upland, presenting a bluff face to the sea. On the top of the cliff, which rises 160 feet above the sea, there is a large table-land, partly covered with an ancient growth of wild olive, and partly brought under cultivation. Between this grove and the ploughed land, at about 500 yards from the brow of the hill, is a long basin without any outlet, having a clay bottom, which fills with the winter rains, and retains the water until it is evaporated by the heat of the summer. The table-land slopes gradually, on the left towards Petrosino, on the right towards Fatago. The surface consists of the yellow sand of the upper tertiary formation. Below this lies a sandy clay, resting on a blue marl. A series of springs bursts out, about 124 feet above the level of the sea, on each slope, showing that the stratification does not dip towards the sea; so that the natural inclination of the beds does not account for the tendency to slip. The under-cliff is therefore supposed to have been washed from the hills by the action of the sea, at a period when the level of the coast was lower than at present. In this under-cliff the blue marl did not appear in the borings until they reached a level lower than that of the sea.

The works undertaken for the protection of the railway at this spot were as follows:—

(1) A retaining wall, to defend the coast from the action of the sea, was constructed, with a thickness at the top of 3·92 feet, and a batter of 1 in 5. The greater part of this wall was based on the blue marl, but a length of about 60 yards was supported on piles.

(2) Protective ditches were cut in the table-land to prevent the further degradation of the face of the cliff by water from the rain-fall draining off the surface. About 3,300 yards of ditch were cut, partly parallel to the course of the railway, and partly in places rendered necessary by the levels of the table-land, so as to drain the low-lying hollows. The ditches, lined with masonry, set in hydraulic mortar, had a minimum incline of 1 in 100.

(3) Two masonry drains were laid, one on the landward side of the railway, and at a distance of about 21 yards, and the other at the back of the sea wall. These communicated by cross drains. In order to sink the drains to their proper depth, the excavation was filled up with broken stone or coarse gravel, so that the action was that of large hollow drains, with a free conduit beneath.

(4) For a length of 40 yards a retaining wall, composed of pilasters and arches, was built to support the scarp of the hill on the landward side of the railway. The ground here was extremely treacherous, consisting of masses of blue marl mixed with layers of

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small gravel, and of sandy clay. Under the influence of the atmosphere and of the rain it was continually subject to a swelling and crumbling action, and it would have been unsafe to leave it without a masonry revetment. The spaces between the pilasters were filled in with rubble stonework, set dry, which allowed any water issuing from the wall to ooze through without mischief.

On arriving at a certain point in the excavation of the main cutting for the railway, a bed of conglomerate of gravel and clayey sand occurred, which supported a stratum of from 3 to 5 yards of movable sand. The unstable nature of the materials was such that it was thought proper to support the base of the slope by a dwarf walling of masonry, set dry, and to bench the whole face of the slope, the inclined portions being carefully covered with turf. A bench of a little more than a yard wide was left at every 2 yards of vertical height, and the face itself was sloped at the incline of 1 to 1.

The engineers were aware of the advantage which would be derived from the completion of the ditches and drains before the commencement of the main excavation, or of the retaining walls. Being, however, pressed for time, they carried on the various works, as far as possible, simultaneously. They encountered, in consequence, much danger, and met with several heavy slips, during the progress of the work. On several occasions the movement of the sandy and clayey material over the surface of the blue marl occurred so suddenly as to break down portions of the retaining wall, which had to be replaced, in detail, with great care, and under the protection of timber props. The system of drainage, when completed, fully answered the expectation.

For the construction of these works above indicated, 65,000 cubic yards of stone and large-sized gravel were required, exclusive of the ballast for the permanent way. This material not occurring in the vicinity, it had to be fetched from two localities at the respective distances of 8 and 9 miles, at first by sea, but subsequently over the railway itself. Notwithstanding the difficulties encountered, the original estimate for this portion of the line was not exceeded by more than 4 per cent. The works in the Torre Vecchia cutting were commenced on the 18th August, 1872, and completed in October 1874; thus occupying a period of twenty-seven months in execution. The cost was as follows—the length of line, as previously stated, being 1,800 yards:—

	£.
1. Land	1,532
2. Earthwork	676
3. Masonry facings	716
4. Retaining wall	13,040
5. Drains	4,728
6. Culverts and passages	1,952
7. Lodge and level crossing	464
8. Permanent way	2,192
9. Sundry works	472
	25,772

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The entire series of works is stated to have acted in the most satisfactory manner. A large stream of water issued from the drains, and the appearance of the whole coast has been improved by the drainage of the soil. The engineers in charge were, in the first place, the Cavalier Forno, and, subsequently, the Cavalier Boetti, both acting under the orders of the engineer-in-chief, Cavalier Bilia, the Author of the present Paper.

F. R. C.

Prussian Railways in 1875.

(Zeitung des Vereins Deutscher Eisenbahnverwaltungen, 1877, p. 117.)

The number of miles opened during 1875 in Prussia was 892; the total length at the end of the year being 10,347. Of these—

15·59	per cent. were	State railways;	
3·16	„ „	military „	
74·01	„ „	private „	
7·24	„ „	„ „	managed by the State.
100·00			

Of mineral lines, not used for passenger traffic, there were—

	Ordinary gauge.	Narrow gauge.
Worked by locomotive . .	365·0 miles.	24 miles.
„ horse. . . .	58·6 „	128 „

The entire capital authorized up to the end of 1875 was £182,288,965; during that year the increase was £5,247,550. In 1866 the capital amounted to £79,779,870, so that during the last ten years it has been more than doubled.

The rolling stock was increased during 1875 by 444 locomotives, 606 passenger, and 7,045 goods wagons; the total number of locomotives amounted to 6,606, of which 6,486 had a mean of 287 HP. There were 4,912 six-wheeled, and 935 four-wheeled tenders. The total number of passenger wagons was 9,682, with 23,409 axles and 454,529 seats. The total number of goods wagons was 139,542, with 285,314 axles, and an aggregate capacity of 16,400 tons; there were 659 post-office wagons, with 1,781 axles.

	£.	s.	d.
The price paid per locomotive was	2,567	0	0
„ „ passenger wagon was . .	165	10	0
„ „ goods wagon per axle was .	75	0	0

The total distance performed by the locomotives was 73,006,344 miles, being 11,654 miles per locomotive against 11,500 miles per locomotive in 1874. The total number of trains was 7,258, or 19·9 trains per day (in the previous year 21·8 per day), with a mean of 46 axles per train. There were consumed, besides 143,653 cubic yards of wood, 1,765,206 tons of coal, or 53·097 lbs. per train mile

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(nutzkilometer), at a total cost of £1,493,000, or 4·8*d.* per train mile.

The number of "axle miles" run was—

——	Total.	Per Axle.	
		1875.	1874.
For passenger wagons	517,126,146	22,101	22,933
For goods wagons	2,550,291,547	9,029	9,287

Every passenger-wagon axle moved was loaded during the entire year with an average of 4·5 persons (as against 4·8 in 1873), and of the seats and standing room there was utilised 23·2 per cent. in 1875, 22·8 per cent. in 1874, and 25 per cent. in 1873. Similarly each goods-wagon axle (whether loaded or not) was, on an average, loaded—

In the year 1875 with 1·99 ton = 41·2 per cent. of carrying capacity.
„ 1874 „ 2·00 tons = 41·7 „ „ „
„ 1873 „ 2·02 „ = 43·9 „ „ „

As regards passenger traffic, the following figures are given:—

1,676,897	persons	in the	1st	class for	70,229,407 miles.
17,353,269	„	„	2nd	„	475,544,858 „
58,871,932	„	„	3rd	„	979,769,904 „
35,334,761	„	„	4th	„	728,619,521 „
2,156,206	military	. . . . .			77,474,084 „
115,393,065	persons	for			2,331,637,774 miles;
against 109,570,671	„	„			2,253,345,505 „ in 1874.
		Being an increase of .			78,292,269 passenger miles.

Or 3·48 per cent., as against an increase of 2·61 per cent. in 1874, and of 12·65 per cent. in 1873, though nearly 7 per cent. of the latter was due to military movements. Of the passengers in 1875 about 87½ per cent. travelled on the branch lines, and 12½ on the main lines.

The total receipts for passengers, including carriages, horses, &c., for 1875 amounted to £7,114,842, being an increase of 5·67 per cent. on 1874, that of 1874 on 1873 being 4·60 per cent.

The distribution was as follows:—

——	1875.	1874.	1873.	1872.	1871.
On branch lines, per cent. . . .	70·44	69·89	68·73	66·93	62·65
On main lines, and through traffic, per cent.	29·56	30·11	31·27	33·07	37·35

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Showing that, with the increase of the branch-line system, the receipts for through traffic are steadily diminishing.

The total receipts for goods traffic were £18,692,192, being an increase of 7·42 per cent. on 1874, that of the previous year being also 7·42.

The distribution was as follows:—

	1875.	1874.	1873.	1872.	1871.
On branch lines, per cent. . . .	36·41	35·92	37·41	38·20	37·02
On main lines, and through traffic, per cent.	63·59	64·08	62·59	61·80	62·98

The total expenditure in 1875 for—

	1875.	Percentage.				
		1875.	1874.	1873.	1872.	1871.
	£.					
Salaries	4,156,908	28·2	25·0	24·4		
Other personal expenses, remunerations, &c. . . .	1,988,252	13·5	17·9	16·8		
Travelling expenses, passenger duty, &c.	603,893	4·1	..	..	46·4	46·0
Office expenses, heating and cleaning of buildings. .	897,283	6·1	6·2	6·0		
Maintenance of permanent way &c.	1,706,499	11·6	11·9	12·5	13·3	13·4
Cost of transport	3,971,618	26·9	29·1	29·7	28·8	27·4
Miscellaneous expenses . .	1,414,657	9·6	9·9	10·6	11·5	12·6
	14,739,110	100·0	100·0	100·0	100·0	99·4

Elaborate statistics and tables are also given about working costs and details of expenditure.

J. D. L.

Italian Railways in 1875. By Prof. Dr. Stürmer.[1]

(Zeitung des Vereins Deutscher Eisenbahnverwaltungen, 1877, p. 121.)

The Author is of opinion that the purchase of all Italian railways by the state is slowly but steadily progressing, and points to the various conventions that have facilitated the execution of this policy. The following figures he acknowledges mainly to have been derived from the official "Relazione statistica delle Strade Ferrate Italiane," laid before the Italian Parliament in

[1] *Vide* also Minutes of Proceedings Inst. C.E., vol. xxxix., p. 356.

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1876, and the "Appunti di Statistica ferroviaria," of Prof. L. Bodio, published about the same time.

The upper Italian railways comprise 2,094 miles, including the Piedmont system, that of Lombardy and Central Italy, that of Venice, the Voghera-Brescia line, and the Florence-Lucca-Pisa state line. The Roman railways comprise 1,037 miles; the southern railways include the southern lines proper with 902 miles, and the Calabria-Sicilian state line with 588 miles. The Sardinian line has a length of 122 miles, the Turin-Ciriè railway is 13 miles long, the Turin-Rivoli 7·5 miles, and the Settimo-Rivarolo is 14·3 miles long. The cost of each was as follows:—

——	Construction.	Plant.	Cost per Mile, including Plant.
	£.	£.	£.
Upper Italian railways . . .	39,963,760	5,564,960	22,080
Roman „ . . .	17,892,440	1,254,280	17,701
Southern „ . . .	15,349,920	1,351,600	18,518
Calab-Sicilian „ . . .	7,860,920	746,000	16,472
Sardinian „ . . .	1,565,960	55,880	13,105
Turin-Ciriè „ . . .	167,120	26,000	13,952
Turin-Rivoli „ . . .	32,000	12,000	5,865
	82,832,120	9,010,720	15,384 average

The rolling stock during 1875 consisted of—

——	Locomotives.	Passenger Wagons.	Goods Wagons.
Upper Italian railways	727	2,175	14,673
Roman „	228	838	3,226
Southern „	207	637	2,976
Calab-Sicilian „	108	452	1,052
Sardinian „	16	41	160
Turin-Ciriè „	5	32	52
Turin-Rivoli „	4	30	5
Total in 1875	1,295	4,205	22,144
„ 1874	1,263	4,053	21,794
„ 1873	1,192	3,919	20,615

For every 62 miles of railway (100 kilomètres) there were 16·8 locomotives, 54·7 passenger wagons, and 288 goods wagons; the corresponding number on German railways being 33 locomotives, 61 passenger wagons, and 721 goods wagons. The consumption of coal in relation to traffic was as follows. (See next page.)

Of the total number of trains run in 1875, viz. 361,488, no less than 250,469, or 69·3 per cent., were passenger trains; whereas on the railways which belonged to the Association of German railways in the year 1873, only 35·8 per cent. of the trains were passenger

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——	Coal in lbs. per Train Mile.	Average daily Number of Trains.	Number of Passengers.	Number of Train Miles.
Upper Italian railways. .	59·58	13·29	17,860,508	9,949,294
Roman „ . .	31·18	9·23	3,747,958	3,410,041
Southern „ . .	40·44	9·62	4,124,321	3,121,963
Calab-Sicilian „ . .	34·88	5·51	1,438,877	1,026,418
Sardinian „ . .	..	5·11	470,063	229,015
Turin-Ciriè „ . .	..	12·61	309,419	59,944
Turin-Rivoli „ . .	..	15·37	303,828	41,738
German railways (1873) .	53·54	20·30	..	..
Total	..	..	28,254,974	17,838,413
„ in 1874 . .	..	..	27,319,675	17,332,018
„ in 1873 . .	..	..	26,254,326	16,522,697

trains; showing to how great an extent goods traffic in the latter country preponderates.

The average number of miles travelled per locomotive was 17,887, of which 13,774 were train miles, so that 23 per cent. of the mileage must be put down to empties or shunting. On the German railways this amounted to 29 per cent. The average number of trains run per day in Italy was 10·1; in Germany during 1873 it was 20·3.

The receipts and expenditure are given in the following table:—

——	Working Length in Miles.	Receipts.	Expenditure.	Receipt per Mile.	Expenditure per Mile.	In Percentage of Expenditure.	Surplus in Percentage of Original Cost.
		£.	£.	£.	£.		
Upper Italian railways	2,051	3,662,944	2,052,936	1,771	993	56·05	3·50
Roman „	1,006	1,035,705	696,583	1,022	707	67·25	1·88
Southern „	889	837,127	581,780	934	649	69·50	1·54
Calab-Sicilian „	510	211,481	203,813	411	396	96·37	0·10
Sardinian „	123	40,195	60,967	325	495	151·68	..
Turin-Ciriè „	13	13,826	6,727	1,053	512	48·61	3·90
Turin-Rivoli „	8	4,916	2,822	655	376	57·40	4·75
Total . . .	4,600	5,806,194	3,605,628	881·6	589·7	78·12[1]	2·61[1]
German railways (1874)	..	..	..	2,623	1,555	59·27	5·17

The receipts per train mile in Italy were 6·44*s*., and the expenditure 4·00*s*.; the corresponding figures for Germany for 1873 being, receipts, 7·05*s*., and expenditure, 4·37*s*.

As regards accidents, with more than 28,000,000 travellers, there was 1 killed in 2,825,497, and 1 wounded in 504,553. In Germany, in 1873, there were nearly 180,000,000 travellers; there being 1 killed in 8,159,410, and 1 wounded in 1,025,754.

J. D. L.

[1] The original has 62·10 and 2·44.

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Sorting Sidings for Marshalling Goods Trains.[1]

By JULES MICHEL.

(Annales des Ponts et Chaussées, 1876, p. 531, 1 pl.)

The sorting of goods trains is accomplished either by ordinary level sidings, or by the help in addition of turntables or traversers worked by steam; or by sidings on an incline, so that the sorting may be done by gravitation. Turntables are employed in England and France, but not in Germany, whilst steam traversers, which are in use in England, are but seldom used in Germany, and have not yet been introduced into France. The method of sorting by gravitation was adopted in the first instance where the main line was on an incline, but now it is more frequently adopted, and when once introduced it has never been abandoned. It has been in use at Dresden for twenty-eight years, at Leipzig for sixteen years, and for thirteen years at Zwickau. The results of sorting by gravitation and by level sidings at various stations in Germany are given in a series of tables.

The advantages of sorting by gravitation are rapidity, saving of space, economy, and safety. In arranging a train the sorting occupied about two-thirds of the time, and each operation takes only three-quarters of a minute when performed by gravitation, but three minutes with level sidings. The saving of space follows from the saving of time, as each portion of the train occupies the sorting sidings for a much shorter period. For instance, taking the mean results from a great number of station sidings, eleven thousand sorting operations per day require 63 miles of level sidings, and only 39 miles of inclined sidings. The average cost price of sorting per wagon is 3·26*d.* on level sidings, and 1·44*d.* on inclined sidings. The safety of sorting by gravitation is shown by a comparison of the accidents from sorting in Prussia (where level sidings only are in use) with those in Saxony, 2·8 men being killed and 6·5 wounded in Prussia for one in Saxony; and the cost of repairs per wagon per mile is five-eighths in the latter country of the cost in the former. The chief danger in sorting arises from the absence of brakes, which are not, as they should be, attached to every truck; and the brakes ought to be so arranged that a man could apply them without having to get on the truck. The cost of such an arrangement would soon be regained by the saving in repairs, and by obviating the necessity, which frequently arises at present, of adding empty trucks to the trains to provide sufficient brake power.

Steam traversers are not suitable for sorting, as they can only convey one truck at a time, and usually return empty, shifting about fifteen trucks in an hour. They are specially

[1] *Vide* also Minutes of Proceedings Inst. C.E., vol. xli., p. 19.

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serviceable on quays and in large goods sheds, where it is important not to interrupt the process of loading, and consequently the employment of a locomotive is inconvenient, and leads to great loss of time. Turntables can also be used with advantage in similar situations. The cost of sorting with horses and by means of turntables is 3·6*d.* per truck, and with steam traversers 2·11*d.*

Passing now to the consideration of the working of sidings on railways in France, the results obtained from level sidings at two stations on the railway from Paris to Lyons and the Mediterranean are given in the following table. The stations selected are Guillotière (Lyons), and Portes, near Valence. The details are given of the working on the largest of the two sets of sidings at Guillotière. This set consists of sixteen lines of way, of which eight are joined at both ends, and there are two sets of turntables, one numbering eleven and the other thirteen, both sets being incomplete, which involves a waste of time in sorting. At Portes, also, there are two sets of sidings, and the details relating to the working of the most complete set are given in the table. The latter consists of eighteen lines of way, seventeen of which are furnished with turntables, the remaining line, which adjoins the main line, being used as a shunting siding for trains. The turntables are inconveniently placed near one extremity of the siding, which makes the time taken in each operation much longer than at Guillotière.

——	Guillotière.	Portes.
Number of trucks sorted per day	1,242	1,150
" " " by locomotives	775	800
" " " by horses	467	350
Number of shunting operations performed by locomotive	85	133
Average number of trucks in each division	9·12	6
Average duration of each operation performed by locomotives, including time lost	12 minutes	18 minutes
Average duration of each operation performed by horses, including time lost	9 "	12 "
Number of trucks sorted per turntable per hour	12	17
Cost of each shunting operation of the engine	2*s.* 1·25*d.*	1*s.* 6·14*d.*
Cost per truck of sorting by locomotives	2·52*d.*	3·02*d.*
" " " by horses	2·38*d.*	2·28*d.*
Actual cost per truck	2·46*d.*	2·78*d.*

A third station, Terrenoire, near St. Étienne, on the same railway, affords a specimen of sorting sidings worked by gravitation. Of the four sets of sidings, the first is composed of five lines of way, and serves for removing from the goods trains, trucks destined for local or branch traffic; the second consists of eleven lines, on which the trucks are sorted; the third has three lines, on which the trains are made up; and the fourth, having six lines, is supplementary to the second. The three first sets have the same gradient, of 1 in 71, as the main line. The arranging, which

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takes place in the first siding, occupies 11 minutes per train, or 3 minutes 7 seconds per section, and the cost is 0·26*d.* per truck. The operation of sorting takes 53 seconds per truck, or 84 seconds for each operation, and costs 1·22*d.* per truck. The next operation, in making up a train, occupies 48 seconds per truck, or about 7 minutes per section, and costs 0·48*d.* per truck. The whole cost of sorting 1,018 trucks, requiring 792 divisions, is £6 16*s.* 2·6*d.*, or 1·60*d.* per truck, and 2·06*d.* per operation; so that per truck the cost is about one-third less, and per operation is about one-tenth of the cost at the other two stations. The actual amount of work, moreover, at the Terrenoire siding could be considerably increased, without materially augmenting the cost, by putting brakes on all the trucks and remodelling the fourth set of sidings. The following tables afford a comparison between the cost of sorting at the French and German stations before named:—

I. SORTING by LEVEL SIDINGS.

	Cost per Section worked by Locomotives or Horses.	Cost per Truck sorted.	Average Time occupied in sorting each Truck.	
	d.	*d.*	Mins.	Secs.
Stations on the Paris, Lyons, and Mediterranean railway.	5·37	2·62	1	66
German stations	6·91	3·31	2	50

II. SORTING by GRAVITATION.

	Cost per Section.	Cost per Truck sorted.	Average Time occupied in sorting each Truck.
	d.	*d.*	Seconds.
Stations on the Paris, Lyons, and Mediterranean railway.	2·06	1·60	53
German stations	3·11	1·36	36

It is evident from the tables that sorting by turntables, as practised in France, is cheaper than the method employed in Germany, but that sorting by gravitation is more rapidly performed in Germany than at Terrenoire in the present imperfect state of its working arrangements. In conclusion, it appears that the most economical way of sorting trains is attained by admitting the train through facing points on to a siding having an incline of from 1 in 125 to 1 in 83, so that the train is sorted by gravitation, and by a steam traverser in the centre of the set of sidings. By this system, provided that all the trucks have suitable brakes, the cost of sorting would be from about 1·34*d.* to 1·54*d.* per truck, even in cases where no previous sorting has taken place. If

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circumstances do not admit of the siding being made on an incline, the sorting must be performed by locomotives, aided by turntables, or, in preference, by steam traversers, in which case the cost would be from 1·92*d.* to 2·11*d.* per truck, if the train is admitted through facing points; otherwise, the cost would amount to 2·30*d.* or 2·50*d.* per truck.

L. V. H.

On the Length of Bessemer Steel Rails. By H. Wernich.

(Organ der Fortschritte des Eisenbahnwesens, vol. xiii., p. 180.)

Owing to the adoption of Bessemer steel rails measuring 29 feet 6 inches in length on the new line "Temesvar-Orsova" belonging to the Austrian State Railway Company, the "Deutsche Eisenbahn Verein" at Munich discussed the following objections to the use of long rails:—*a.* The difficulty of obtaining a good and cheap material; *b.* The increased labour in loading and unloading; *c.* The larger play to be allowed for variations of temperature; and *d.* The greater loss of material when renewal is necessary on account of single defective parts.

To refute these objections the Author shows the general adoption of steel rails, the progressive improvement in their quality, and the decrease in price, and gives the grounds on which he bases the opinion that the above objections are untenable. Referring to rails 60 feet in length which have been satisfactorily manufactured in America, he says in reference to objection *a*, that on four railways the renewals per 1,000 rails annually were as follows in the years indicated:—

Year.	Lower Silesian.	Upper Silesian.	Westphalian.	Köln-Minden.
1867	2·83	3·46	34·28	4·30
1868	1·14	5·86	35·71	2·50
1869	2·71	3·80	..	2·77
1870	0·51	1·72	1·25	1·53
1871	1·27	0·78	3·80	2·16
1871–2	1·51	..	..	..
1872	0·16	1·18	0·49	0·56
1872–3	0·44	..	..	..
1873	..	0·75	0·37	0·23
1873–4	0·45	..	..	..
1874	0·09	0·59	0·63	0·28

The renewals in 1867 were to those in 1874 as 28 to 1, or if the Westphalian be omitted, as 11 to 1; while the number of steel rails laid on Prussian railways has risen from 1,540 Bessemer rails in 1867 to 1,393,382 in 1874.

The following diagram shows the reductions in the price of steel

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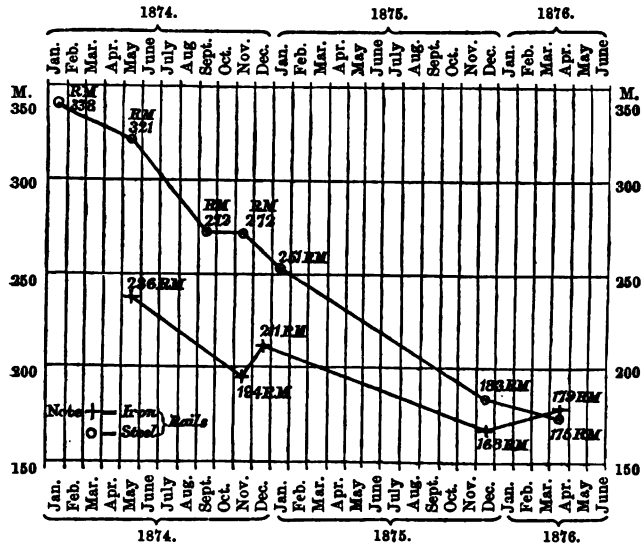
rails in comparison with that of iron rails in 1874–5 and part of 1876 :—



N.B.—The figures indicate Reichsmarken or shillings per metric ton for Berlin. The makers of the rails indicated by the figures are—

+ Iron.	⊙ Steel.
168 RM. Union Co., Dortmund.	175 RM. Union Co., Dortmund.
179 „ „ „	183 „ Bochum Co.
194 „ Jäger & Marcotly, Magdeburg.	251 „ F. Krupp, Essen.
211 „ Hoerde Co.	272 „ Bochum Co.
236 „ „ „	272 „ Phœnix Co., Ruhrort.
	321 „ „ „
	338 „ Iron & Steel Works, Osnabrück.

As to objection *b*, the Author maintains that the lighter weight of steel rails proportionately lessens the labour required to handle them. Most railways belonging to the Deutsche Eisenbahn Verein have adopted rails 21 feet 8 inches long, weighing 4 cwt. 3 qrs. 19 lbs. The rail 29 feet 6 inches long would weigh 5 cwt. 3 qrs. 10 lbs. Taking the capacity of a man at 3 qrs. 26 lbs., a rail 21 feet 8 inches long, weighing 4 cwt. 3 qrs. 10 lbs., would require five men, and a rail 29 feet 5 inches long, weighing 5 cwt. 3 qrs. 10 lbs., would require nearly six men. The labour is thus increased 16·33 per cent., but the increased amount of road laid would be 36·3 per cent., or more than double the increase of labour.

As to objection *c*, the Author states that the increased amount of play to be allowed at the joints of rails 29 feet 6 inches long is little more than that required for iron rails of 21 feet 8 inches long.

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The increase of length of steel for 1° cent. is 0·0000108 of its length at 0°; the increase of length of iron for 1° cent. is 0·0000123 of its length at 0°.[1]

If, according to Winckler, δ = the play at the joints, t = the temperature at the time of laying the rails, t_o = the maximum temperature, l = the length of rail, and a = the co-efficient for 1° cent., then $\delta = a\,(t_o - t)\,l$, or adopting $\delta = 0{\cdot}079$ inch when $t_o = 40°$ cent., then for rails 21 feet 8 inches long $\delta = 0{\cdot}0123\,(40 - t)\,6{\cdot}6 + 2$, and for rails 29 feet 6 inches long $\delta = 0{\cdot}0108\,(40 - t)\,9 + 2$, hence the following table:—

t Deg. Cent.	Fahr.	Play in Inches.			
		Iron Rails.		Steel Rails.	
		21 feet 8 inches.	29 feet 6 inches.	21 feet 8 inches.	29 feet 6 inches.
°	°				
+ 40	104	·079	·079	·079	·079
+ 30	86	·110	·122	·106	·118
+ 20	68	·143	·165	·134	·157
+ 10	50	·173	·208	·168	·193
± 0	32	·205	·252	·189	·232
− 10	14	·240	·295	·220	·271
− 20	− 4	·271	·339	·248	·307
− 30	−22	·303	·382	·276	·346

Thus, in the extreme case of a temperature of − 30°, the play for a steel rail 29 feet 6 inches long is 0·346 inch, or 0·043 inch more only than that required for an iron rail 21 feet 8 inches long.

As to objection *d*, it is necessary to note the difference between the expressions "wear" and "destruction," or "ordinary" and "extraordinary" wear and tear; or, according to Pollitzer, between the natural decay or wearing out, and the unnatural destruction caused by failures of manufacture or material brought to light by a slight mechanical impulse. According to Garcke,[2] the extraordinary wear and tear arising from the nature of the material, in accordance with the chemical conformation and the working of the raw material, is divided into, Fracture, Bulging, Crushing, caused by faulty make, principally of welding; while destruction either of the vertical or horizontal piling must be divided into, 1, vertical; 2, horizontal; 3, combined separation.

The greatest cause for renewals in steel rails is breakage. Out of 1,393,382 steel rails laid on the Deutsche Eisenbahn Verein up

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[1] *Vide* Péclet, E., "Traité de la Chaleur," 2nd ed., vol. i., p. 12.

[2] *Vide* Zeitschrift für Bauwesen, vol. xxiv., p. 210, "Material, Manufacture, and Wear of Rails."

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to the end of 1874, 3,920, or 0·21 per cent., had to be renewed, from the following causes:—

1.	Fracture through the clinching . . .	94 rails.		
2.	„ „ fish bolt-holes . . .	462 „		
3.	„ „ the entire section . .	1,622 „		
		2,178 „	= 0·16 per cent.	
4.	Other causes	742 „	= 0·05 „	
	Total	3,920 „	= 0·21 „	

The proportion of renewals through breakages to that from other causes was as 2,178 to 742, or nearly 3 to 1. Since, however, 75 per cent. of renewals on all the Prussian railways were due to the same cause, the Author, without investigating the actual conditions of manufacture, mode of treatment, &c., gives the following table:—

Works where Rails were made.	Number of Bessemer Steel Rails laid to end of 1874.	Renewals in consequence of Breakage.						Percentage of Rails renewed.	Number of Rails per 1,000 renewed per Month.	Percentage of Renewals by Breakage to Total Renewals.
		Through the Clinching.	Through Fish Bolt-holes.	Through the whole Section.	Generally $\Sigma(d+e+f)$.	From other Causes.	Total.			
Krupp, Essen. .	611,448	48	285	263	596	213	809	0·132	0·038	74
Bochum Co. . .	202,745	8	59	178	245	77	322	0·159	0·049	76
Hoerde Co. . .	173,693	29	74	325	428	102	530	0·305	0·086	80
Osnabrück Works	134,969	2	8	660	670	17	687	0·509	0·312	97
Neu Schottland „	79,544	1	4	115	120	40	160	0·200	0·084	75
Dortmund „	48,882	5	..	14	19	4	23	0·050	0·044	83
Ruhrort „	44,104	Not clinched	1	3	4	..	4	0·010	0·006	100
Gute Hoffnüng „	39,399	„	..	12	12	29	41	0·100	0·076	30

In conclusion, the opinion is expressed that the introduction of rails 29 feet 6 inches long has the advantage of lessening the cost of joints and fastenings to the extent of 128 joints per mile, and may be considered an advance in railway construction.

W. E. T.

Measures for the Development of Rail Production in Russia.

(Russian Mining Review, St. Petersburg, vol. iii., p. 370.)

In 1875 an Imperial Commission was instituted to inquire into the supply of Russian railways with rails and rolling stock. The report of that Commission led to the following measures being adopted by the Government.

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1. Not to allow any rails to be imported free of duty, either for the railways now being constructed and concessioned, or for those already existing, unless previously guaranteed against any such measure.

2. The statutes of the future railways to include the obligation to obtain in Russia not less than half the quantity of iron and steel rails required for the first establishment and also for renewals; and the rails which will be imported from foreign countries to be subject to the payment of established duty.

3. A premium to be granted per pood for steel rails manufactured in Russia for private railway companies, during twelve years, commencing in September 1877; and for those rolling mills or works which will be established and work with native pig iron, commencing in September 1879. The premium to be as follows: during the first eight years, 35 copecks per pood of steel rails (£2 14*s.* per ton); during the ninth year, 30 copecks per pood (£2 6*s.* per ton); during the tenth year, 25 copecks per pood (£1 18*s.* per ton); during the eleventh and twelfth years, 20 copecks per pood (£1 11*s.* per ton). At the same time, the Ministers of Finance and of Ways and Communications are invited to take measures to lower the freights for mineral fuel, iron ores, wrought iron and pig iron.

The import of foreign rails was—

	Poods.	Tons.
In 1872	6,002,167	(96,809)
In 1873	9,070,367	(146,296)
In 1874	10,911,404	(175,992)

In the first half-year of 1876, there were imported 3,219,315 poods (35,795 tons) of Bessemer steel rails, or more by 330,230 poods (5,326 tons) than in the first half of 1875.

N. O.

Carriage Traverser worked by Endless Rope. By P. LEONHARDI.

(Organ für die Fortschritte des Eisenbahnwesens, vol. xiii., p. 85, 1 pl.)

The central repairing shop of the Rhenish railway at Cologne is divided into locomotive and wagon departments, the latter comprising smiths' and tool shops, and large sheds for carpenters' and tinmen's work extending over about 8 acres. The area is calculated to allow 5 per cent. of the wagon stock to be under repair, one-third of which, or two hundred and thirty wagons, can be placed under cover. There are four traversing carriages in the shop, so arranged that any wagon can be taken in or out without any of the other wagons requiring to be moved for the purpose. As the shop is 460 feet by 492 feet, quickness of motion is desirable for the traversers, and this has been ob-

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tained by applying to them the principle of Ramsbottom's cranes, moving two carriages by one endless rope. The gear is so arranged that each traverser can be worked independently of the other and in either direction, and that wagons can be moved either on to the traverser or removed from it. The rope takes its motion from the steam engine driving the wood-working machinery: it runs over pulleys sunk between the rails of one traverser, and returns between those of the other. At one point it is also made to pass through a funnel of strong leather filled with a mixture of tallow, wax, and blacklead, to protect it and prevent its wearing. In order to keep it tight it is made to pass over a pulley having sliding bearings and acted on by a chain and dead-weight. The moving of the traversers is thus effected: The driving rope is led round two pulleys on the traverser frame, so as to impart to them opposite motions. By means of friction clutches either of these pulleys can be put in a gear with a larger wheel placed between them, which is in connection with one of the axles of the traverser: thus by gearing with one or the other of the pulleys the traverser can be moved in either direction, or by means of a double friction clutch this motion can be stopped and another wheel put in gear instead which actuates a rope barrel. The end of the rope can be attached to a wagon, which thus is drawn on to the traverser; or if the rope is made to pass round a fixed pillar previous to being attached to the wagon, the latter can be drawn off the traverser. The velocity of the driving rope is 56 feet per second, while that of the traverser is 3·28 feet, and that of the wagons, when being drawn to the traverser, 12·8 inches per second.

According to experiments conducted by the Cöln-Minden railway at Deutzerfeld the resistance of a loaded traverser is = 440 lbs., its total weight being nearly 20 tons. Two men are sufficient to attend to the four traversers by turns, whilst six to eight men would have been required for each if worked by hand.

W. R. B.

Principles of Tidal Harbour Improvement, as applied at Wilmington, Cal. By C. B. Sears.

(Transactions of the American Society of Civil Engineers, vol. v., p. 388.)

In the most perfect type of a tidal harbour, the waterway sections decrease gradually from the sea inland, expand into a basin of large area, and thus form a reservoir for the temporary storage of the high tides. In any work of improvement which includes a construction exposed to the action of the waves, the direction of its axis should be as nearly as possible parallel to their direction. If there be several entrances, of which only one is to remain open, the choice should fall upon the one which conforms most nearly with the direction of the prevailing fair-weather

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winds. Its shape should be tunnel or trumpet-mouthed, but the low-water sectional area should contract as little as possible, and any artificial work to close an entrance should follow the general contour of the work or shore on the opposite side. The scouring power of water in motion, being in ratio to the square of the velocity, depends upon spring rather than neap tides. The ebb tide has a *vis viva* from six to eight times that of the flood; the latter attains it maximum velocity about the end of the third quarter, that of the ebb tide obtains at the beginning of the third quarter, and is maintained well into the fourth.

The entrance works of a tidal harbour, therefore, should be so arranged that they will not, by ponding back or retarding the last of the flood tide, prevent the full accumulation of water in the upper and higher reaches, but will allow a free inflow, and direct the last of the ebb tide along a definite channel, and take advantage of the best of its working force. For this purpose a work, of which the top level is bare at half-tide, will be most suitable, while the trumpet-shaped entrance aids the flood in its filling action. In any system of training walls or low jetties for producing a scour in the channel, or on the bar, their height should be in ratio to their distance from the entrance, those near the latter being the lowest, the innermost being highest; this insures a ready flow for the flood tide, while the ebb is guided and concentrated in its last stage. Great single lengths of wall should go with low altitudes, and the converse; as in the upper reaches of an estuary the channel may be narrow, in which case the average section must not be lessened. The general object is to concentrate the tidal currents on one given axial line, without excluding tidal water from the estuary.

At no distant geological period the ocean on the coast of California extended far inland beyond the village of Wilmington, along the valley of the San Gabriel, now an insignificant stream, but formerly a large river. The bay, exposed at low water, consists of mud overlying clay. To the east a wide stretch of sandy soil terminates in a range of bluffs of friable sandstone overlaid with adobe clay. Following the shore towards the west, is a stretch of hard sand beach about 200 feet wide at low water and 5 miles long. At its end a small channel, 200 feet wide at high water, and almost dry at low water, forms what is called "Rattlesnake Island," 2 miles long, the growth of which westward was going on in 1871, though slowly; and which is known to have advanced in a south-easterly direction several hundred feet in the last fifty years. At Wilmington wharf the low-water mid-channel has a depth of 5 feet, the top width being 150 feet, deepening outward with a maximum depth of 20 feet toward the bar. At the south end of the Rattlesnake Island the whole tidal energy is concentrated through a channel 800 feet wide at low water, with a maximum depth of nearly 20 feet. Southward, where the island terminates, the ebb tide begins to escape seaward over a broad sandy flat, 3,700 feet wide, the greater volume, from the impetus received, keeping the

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main low-water channel, hugging the bluff shore of the mainland, until deflected by a hard pan-formation towards San Pedro point, and turned to the ocean eastward over a flat 3,000 feet wide, and not more than 4 feet deep at mean low water, a portion ebbing south over a flat 2,000 feet wide, and with a maximum depth of 7 feet.

Surrounding conditions suggested the connection of Rattlesnake and Deadman's islands. The estuary flats are 3 feet above mean low water, so that the average clear regular tidal prism on high springs is about 3½ feet, making a volume of water exceeding 198,000,000 cubic feet, or nearly 1,500,000,000 gallons, all passing through the tidal gateway, between the south end of Rattlesnake Island and the mainland, the average maximum surface velocity being 4·4 feet a second, or 3 miles an hour, the sub-velocity being somewhat greater, and increasing near the bottom, and the low-water sectional area being about 8,000 square feet. This velocity was maintained for two-thirds of the distance seaward towards San Pedro point, when it fell off rapidly to 2 miles, and over the bar 1½ mile per hour, or 2·2 feet per second; with a guiding work, a velocity of 3 miles per hour was anticipated, modified by the necessity of converging the entrance and giving it a greater width seaward, while the existence of a boulder reef between San Pedro and Deadman's Island required artificial removal.

The work constructed between Rattlesnake and Deadman's islands is formed axially on the plan to reversed curves. The first curve, the radius of which is 2,000 feet, is convex to the harbour, and the reverse curve, the radius of which is 4,000 feet, is concave to the harbour. It was determined to build at least 4,700 feet of close piling, 8 feet above mean low-water, which, while shutting off the highest tides, and breaking the force of the heaviest storms, would permit the ocean swell at high water to throw large masses of water over the work, which would have to find its way over the bar, adding thereby to the scouring force, while by allowing sand to lodge against the work on the inside, it would increase its stability and keep out marine worms.

The first 100 feet, having but one thickness of sheet piles, gave great trouble, as the water worked through it and created potholes. The next 3,600 feet had two thicknesses breaking joint. The first construction having been remedied at great expense, was considered safe for two years, as the waves had banked the sand against it to the top and to the width of several hundred feet. A storm, however, coincident with a high tide, sent the surf over this bank, washed out the sand, worked round the initial point of the piling, leaving a high-water channel, to remedy which a solid bulkhead was built, and the 100 feet of faulty construction were filled up on both sides with a solid mass of gravel and cobble stones. At the end of the second construction, 3,700 feet from the shore, where there was deep water and the work was more exposed, 1,000 feet of two rows of timber sheet piling were constructed, 10 feet apart, with inner and outer longitudinal wales, at low

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water and just above high water, the intervening space being filled solidly with boulders and broken stone up to the top.

As the work advanced, undermining began, 16 feet vertically on one side, the piling holding on in places with only 4 feet penetration. To counteract this, box cribs 24 feet by 6 feet by 4 feet were sunk at intervals of 60 feet at right angles to the work, filled partly with sand, and on the top sandbags and bundles of brush loaded with sandbags were put down to break up the local currents. These efforts were successful, though they had nearly proved ineffectual, for when scouring ceased, the average pile penetration was only 4 to 6 feet to resist the buoyancy of 14 to 16 feet of timber and the impact of the waves. Sand gradually accumulated, and the work stood the hardest winter's gale, which piled the sand against its entire length.

The Author then gives minute details of the manner in which the pile-work and scaffolding were erected. The first work was commenced on the 2nd October, 1871, by contract at $3·15 per lineal foot for the first construction, and $5·83 per lineal foot for the second. When 347 feet had been completed, the contractor threw up his contract, and the work was continued without a contractor, active operations being commenced by the end of May 1872. By the end of October the whole of the timber work, 4,700 feet long, had been completed, comprising 2,750,000 cubic feet of timber and 137,000 lbs. of iron. At right angles to the main work, at intervals of 150 feet, groynes were built, 30 feet long, to check the undermining action of the currents. They alleviated the lateral scour, but did not help that in advance. The work had to be constantly watched, as several times portions were swept away. Soundings were taken each day every 5 feet along each side, and plotted every evening on a plan, thus giving a daily contour of the bottom, and showing the penetration.

The plate of the extension of Rattlesnake Island, along the work, in September 1875, shows the first 800 feet of the new formation well covered with small dunes, each supporting a vigorous growth of sand plants. No perceptible deepening of the channel was observed for some time after the completion of the works. The bar was being shaved off uniformly over its whole area, and it was feared that the increased velocity would waste itself, by carrying the bar bodily outside the mouth, where it would be much more difficult to treat. To concentrate the currents, a transverse training wall or jetty was constructed in a south-west direction, 300 feet long, and rising to mean low water; the beneficial effect was immediate and marked, in consequence of which it was extended to 600 feet, and the first length of 300 feet was raised to half-tide.

The combined effect of the main work and the two jetties was very marked. At intervals of three months elaborate surveys were made and plotted. A depth of 6 feet had extended 700 feet beyond San Pedro point, then the water shoaled to 5 feet for 150 feet, when there came another depth of 6 feet for a length of 400 feet

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and a width of 200 feet. In September 1875 the 6-feet channel had worked clear outside, but had bifurcated into two channels, one over to the West Jetty and the other to Deadman's Island, and a contract was entered into for dredging through the reef between Deadman's Island and San Pedro. In 1872 the depth over the bar was barely 18 inches; in December 1875 the depth was 6½ feet, or an absolute gain of 5 feet, making the tonnage capacity of the harbour eighty-one times as great as it was originally. The total cost of the work, including interest on plant, amounted to £39·82½ per lineal foot.

J. B. R.

Repairing Slip at Palermo. By W. Theis.

(Zeitschrift des Vereines Deutscher Ingenieure, vol. xx., p. 683.)

As soon as it was determined by the harbour authorities at Palermo to draw steam-ships up an inclined plane, for repairs and to remove scale, a choice had to be made between two systems. In one, a car resting on a number of wheels is employed, in the other, a sledge: so that the friction which has to be overcome in drawing up the vessel is in the one instance a rolling, in the other a sliding one. Doubtless the former plan has many advantages; the machinery, chain, and vehicle can be lighter and cheaper, the wear of the working surfaces is less, a considerable saving is effected in tallow and oil, and the difficulties of launching are greatly diminished.

In this instance, however, a sledge had to be chosen, on account of the peculiar configuration of the ground. The borders of the harbour of Palermo are of Portland stone, being a continuation of Monte Pellegrino, and the slope of the bank is prolonged some distance below the surface of the water, when it ends precipitously. As the length of the way is limited at the upper end by the street leading to the mole, and as the inclined plane could not be prolonged seawards without enormous expense, the space available was enough to admit of a slide, but not of a line of rails, the incline of which would have to be far less, and therefore proportionately longer.

The slip consists of the inclined plane, the sledge, the track on which the sledge glides, the chain, the hydraulic apparatus, pumps, steam engine, launching presses, &c. The part of the inclined plane above the level of the water is of masonry, of extra strength under the hydraulic presses. Below the sea-level hydraulic mortar was used, and the rock on which it was placed was first carefully freed from mud. Before this mortar could set it was smoothed and brought to a proper angle by a wooden template, sliding on temporary parallel guides.

The way is formed of a large number of cross sleepers, on which

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four strong beams are placed longitudinally. Above the water-level these are fixed, but the lower part is connected by hinges, and floats as soon as the weight is taken off. For the removal of the rudder a hole is made in the middle of the inclined plane near the surface of the water. On the centre beam is a trough of sheet iron for the chain. The sledge is made of strong oak, wedge-shaped blocks slide in guides on its cross pieces, and on these are placed supports which take the curve of the ship's side. When a ship is to be drawn up, the sledge with all its supports is let down under the keel and fixed up to it. The props are then drawn close to the ship's sides by means of ropes, and as the stops prevent them from sliding back the sledge and ship form one compact body. The whole is then brought to the inclined plane by the capstan, placed parallel to the way and in the middle of it, and then drawn up by the chain.

The hydraulic presses rest on strong cast-iron plates, let into the brickwork and surrounded by concrete. There are two pairs working alternately, and the stroke of the piston, 5 feet, is half the length of a link. The links, weighing 16 cwt. each, are lifted up one by one by an over-head traveller, placed on one side.

A 40-HP. steam engine, by means of gearing, sets the pumps of four presses in motion, whose safety-valves are so loaded that by the greatest pressure two pistons are put out of work; when the pressure is somewhat less, three pistons are at work; whilst at the normal pressure all four are engaged. When great frictional resistance suddenly takes place, by sand getting on the ways, or from other causes, the machine is not stopped, but there is a diminution of speed equivalent to the loss of power. A regulator, similar to those used on marine engines, is employed to keep the engine from exceeding the appointed maximum speed. An air vessel, from time to time refilled, was afterwards connected with the pressure pipes, and has rendered good service by lessening the clapping of the valves, formerly very noticeable, especially when the pistons of the presses came to the end of their stroke.

The time required to clean the hulls of vessels, to paint them, and to allow the paint to dry, is not less than eight days. At the end of that time the frictional resistance to the downward movement of the ship is often considerably greater than the downward strain caused by its weight, especially when the sirocco wind has melted away the tallow from under the sledge. Two hydraulic presses had therefore to be provided in order to commence the downward movement. The piston diameter of these presses is $7\frac{7}{8}$ inches, and the stroke 6 feet $6\frac{3}{4}$ inches. They are connected with the pressure pipes of the other presses by a special valve, and the pressure is communicated to the sledge by means of strong beams. Once in motion, the ship slides downwards with increasing velocity, till it reaches the water, by the resistance of which it is gradually stopped.

It is found by experience that a ship can be conveniently

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launched at an inclination of 1 in 13·3, provided that no immediate contact takes place between the surfaces of the wood, but that they be separated by a thin layer of grease. However carefully polished the surfaces of the wood may be, the adhesion is always greater than the downward strain, unless diminished by the use of tallow. For this reason an inclination of 1 in 13·3 has been adopted, and as the friction during the downward movement of surfaces of the same description is equal to the friction during the upward movement of the same surfaces, the frictional resistance during movement must be equal to 7½ per cent. of the total weight. It is also found by experiment than an additional 5 per cent. must be allowed for increase of friction during rest; and, furthermore, as, in drawing up, 7½ per cent. of the weight had to be lifted, the pressure of the two hydraulic pistons must be equal to 20 per cent., or ⅕ of the united weight of sledge and ship. The press-pistons have a diameter of 12½ inches, giving an area of 124 square inches. The maximum pressure is 4,500 lbs. on the square inch, so that there is a pressure of 480 tons for both pistons. With this apparatus, therefore, it is possible to draw up a load of 5 × 480 = 2,400 tons; or, as the sledge with the chain weighs 200 tons, a ship of 2,000 tons dead weight.

The press-pumps have pistons 3⅜ inches in diameter and $6\frac{5}{16}$ inches stroke. They make forty double strokes per minute, drawing the sledge about 125 feet forward per hour; and as the ways are about 375 feet long, the operation of drawing up takes about three hours. The links are forged from old Low Moor plates. They are $3\frac{9}{16}$ inches thick by $1\frac{1}{16}$ inch deep, and are calculated to stand a strain of 1,000 tons. The apparatus has been in constant work for two years, during which time only two links have broken. The pins of the chain have a diameter of 5½ inches.

W. W. W.

Accident to a Caisson at the Willems Bridge, over the River Nieuwe Maas at Rotterdam. By D. A. Wittop Koning.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1875–76, p. 144, also 1874–75, p. 138.)

An accident of a serious nature occurred during the sinking of the caisson for that pier of the railway bridge which is close to the quay wall of the town. Excavations had to be made in the caisson under compressed air, supplied by two force-pumps on a staging erected on piles round the caisson. The latter was of oblong shape, 84 feet 7 inches long by 24 feet 6 inches wide, with semicircular ends. It consisted of two chambers; the lower one was 11 feet 9 inches high, with sides of wrought iron lined with brickwork, with a roof of concrete and brickwork carried by iron beams; the upper chamber, fixed upon the roof of the former, was constructed

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of wrought-iron segments, bolted together, and stiffened inside by angle irons and a strong lining of brickwork. Four shafts connected the chambers; two for materials, and two for the workmen. The caisson was built ashore upon a slip, and was floated out to the site between two pontoons, air being pumped in to keep it floating. Having arrived over its position, the staging was closed around it, and bricklayers were set to work to carry up the lining; the pier thus gaining weight, sank gradually.

Unfortunately, however, the cutting edge at the north side struck the piles of the surrounding staging, and the caisson, being held up at one corner, went off the level. Air was pumped in again, but, though the rising tide lifted it off the piles, it struck some boulders which had been thrown around the caisson to prevent scour. The south side, now clear of the piles, continued sinking, and, in spite of all efforts, could not be stopped until the pier was leaning at an angle of 45°, having considerably damaged the surrounding staging in its course.

The contractor saw no other way of bringing the caisson back into its place, except by tackles fastened to an anchorage on shore, which would have been no easy task, owing to its great weight and unfavourable position. The tackles would have required chains to be passed round the caisson, and it was feared that the latter would not be strong enough to withstand the pressure, and would either have parted from the lower chamber or collapsed. It would have necessitated on shore strong and expensive anchorage in the soft strata behind the quay wall, and it was calculated that a force of 1,000 tons, by means of fifty cables, each bearing a strain of 20 tons, would have to be applied.

Among the numerous proposals, that of the Author was selected. He advised the building of a cofferdam inside the caisson, which, when pumped dry, would, as he demonstrated, yield a floating power three times greater than required. Amongst other advantages, his scheme obviated all danger of bringing the pier up suddenly. The lifting force had its greatest leverage at the moment when the greatest force was required, namely, in the beginning, diminishing gradually until the pier was in a vertical position, and its centre of gravity in the same vertical line with the centre of flotation.

The dam was commenced on June 15th, 1875, and consisted of double-grooved sheet piling, 39 feet long, 10 inches thick. At first each pile was set separately, by a diver, in a seat cut for it in the brickwork. As the work progressed, it was found advantageous to set them in sets of four at a time. They were pressed together by a windlass, and the joints were caulked with oakum. In spite of this precaution, much trouble was encountered through leakage. After spreading a tarpaulin over the outside of the dam, two centrifugal pumps, driven by two portable engines, were started on September 24th, the diameter of one being 7 inches, that of the other $4\frac{3}{4}$ inches. When a difference of 3·15 inches between water-levels was observed, the

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pumps had to be stopped and the leaks repaired. It appeared that the dam had come away from the ironwork at the east end, and a considerable leak had to be stopped with old sacks and clay. Pumping was recommenced on October 7th with five pumps and five engines. A difference of 4 feet 4 inches was attained, whereby the first definite rising of 2·36 inches was noted. By this mode of working, the angle was reduced from 45° to 22° 25′ on October 28th, when the greatest difference between water-levels, 16¼ feet, was noted. It was now decided to apply mechanical power by chains and crab-winches. On November 1st, when the pier stood at an angle of 16° 45′, the west cable parted, the links being 0·98 inch thick. It was made good, and work resumed with a strong flood tide, when the last cable, with links 1·34 inch thick, gave way. Accordingly it was determined to have recourse to compressed air in the bell, which was forced in on November 3rd. This was followed by an immediate rise of the pier, and improvement of the angle. The inclemency of the season now put a stop to further work. In the meanwhile everything was prepared to start with a fourth method, consisting in the application of screwjacks, applied to the south side of the caisson, arrangements being made to prevent the north side from rising, so as to cause the caisson to move bodily to the southward. This effect was still further increased by casting more rubble stone on the north side. During this work, 2,000 tons of stone were tipped on the north, but none on the south. Bad weather continuing, the travellers were erected; the staging was finished and protected against ice-drift, and the iron skin of the caisson was carried up to withstand the extraordinary height of the tides. On January 27th, 1876, it was first possible to start screwing up, the clay having been removed from inside the south side to lessen the resistance; and on February 9th the latter rose 19·68 inches, reducing the angle to 3° 50′. The lifting was then stopped; the screws were wedged up, and the air let off. During this period, the sinking of the pier to its ultimate depth, and the building up of the brickwork slowly advanced. By distributing the brickwork, and by careful excavation, the pier was brought quite upright. The work was greatly impeded at this time by high tides. On May 24th—one year and three weeks after the commencement of operations—the pier reached its ultimate depth.

In its fall it had slid from its proper position to the northward, so that at the east end it was 6·9 feet, and at the west end 8·36 feet from its intended place. By tipping a bank of rubble on the north side, the displacement was reduced at the end of the second period to 5½ feet at the east end, and 7½ feet at the west end. Afterwards this was further reduced to 19·68 inches and 4 feet 5 inches at the respective ends, so that no alteration of the superstructure was necessary.

A. S. M.

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Improvement of the River Aar between Thun and Uttigen.

By J. ZÜRCHER.

(Allgemeine Bauzeitung, vol. xli., pp. 65 & 79.)

This work was rendered necessary in consequence of the silting up of the bed of the river, and of the inundations resulting therefrom during floods, which injured the neighbouring property, and threatened the embankment of the Berne and Thun railway.

The Aar is the outfall of the lake of Thun, and has a minimum discharge of 800 cubic feet, and a maximum of 15,000 cubic feet per second. For more than 2 miles it runs between well-defined banks and over a tolerably uniform bed; but at the end of this reach the Zulg, a mountain torrent with a fall of 70 feet per mile, and heavily charged with detritus, joins it, and changes its character.

On the opposite, or south bank, another tributary (the Kander) formerly fell into the Aar, and brought down a large amount of alluvium; but in 1714 it was diverted into the lake of Thun higher up, and the old bed is being gradually planted with fir trees.

The whole plain between Thun and Uttigen is formed of the deposits of these tributaries; and the Aar ran through it in a very tortuous course, winding about no less than six times in the distance under report. Protective works had here and there been built by the railway company and by the neighbouring landed proprietors; but as these works answered imperfectly, application for assistance was made, in 1870, to the Bernese administration, and the undertaking which forms the subject of this Paper was sanctioned.

The total length of the new cut is 12,600 feet, divided into three sections of 5,000, 4,000, and 3,600 feet. The first section commences with a curve of 1,380 feet, described with a radius of 63 chains; the last ends with a curve of 4,700 feet, described with a radius of 95½ chains, the intervening portion being straight. The difference of level at low water between the two ends is 33·2 feet, or 13·7 feet per mile.

The breadth of the cut is about 130 feet, but of this only 30 feet and the slopes on each side were excavated, the remaining portion being washed out by the scour of the river: the depth is 10 feet. The faces of the slopes are revetted with stone to a depth of 1½ foot, and the foot was protected by three Gumpenberg rollers or gabions, 3 feet in diameter, filled with stones. The Zulg tributary is diverted from its old course, and enters the Aar farther down stream in a straight cut, making an angle of 50° with that river. Its breadth is 50 feet and its depth 6 feet. It was treated in a similar manner to the Aar, that is, a breadth of 20 feet was excavated, and the remainder scoured out by the force of the water. The slopes, too, are similarly revetted; but instead of the Gumpenberg rollers, the foot rests on a wooden grillage bedded on a rubble

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foundation 1½ foot deep. To guard against extraordinary floods, embankments with rather flat slopes are built parallel to the river along the whole course, with a berm space of 12 feet. The slopes are protected by a stone revetment and Gumpenberg rollers, as in the case of the river banks.

The original estimate was as follows :—

	£.
Earthwork	1,373
Revetment	11,170
Land compensation and contingencies .	1,137
	13,680

but this was exceeded by 15 per cent. in consequence of a rise in the price of labour and materials during execution.

As the whole undertaking could not be completed in one year, it was decided to commence from the upper end and work downwards. This would have the advantage of giving immediate protection to the railway embankment on the old bed of the Kander (Kandergrien), to which the Aar was rapidly advancing, and the silt, which was washed out of the new cut, would go to fill up the old bed and the numerous channels and creeks intersecting the alluvial plain. Valuable land would thus be reclaimed. The work was commenced in the autumn of 1871 by excavating the first section, and went on satisfactorily till March 1873, when an extraordinarily heavy flood occurred, which breached the embankment, but the damage was fortunately soon repaired. In 1873 the scour had deepened the canal or cut 4 feet at the head and 3 feet halfway down, but the lower end had silted up 2 feet. In two months, the first section of the new cut was washed out to its full width (130 feet), and the material removed deposited and spread over the area included in the second section. This latter was commenced in the autumn of 1873; the excavated cut was completed and the slopes revetted the following spring, just in time to protect it from the scour of an exceedingly high flood. Fortunately the action of the latter proved most favourable, for it scoured out the bed to the full width in a short time, and continued its course in the third section for 1,200 feet, in as straight a line as if it had been traced out—another proof of the advantage of having worked from the upper end downwards.

The winter of 1874–75 was spent in the revetment of the slopes throughout the whole length of the completed sections, and in 1876 the last section was taken in hand.

The Zulg was treated in a similar way, and as the velocity was so great, the scouring advanced rapidly; but extra precautions had to be taken to protect the south bank of the Aar opposite the point of junction by digging foundations for the rollers there employed. As the bed of the Zulg is 5 feet higher than that of the Aar, it discharges into that river by a masonry overfall. The deepening of the bed was continued up the river for more

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than a mile above the new cut, and here the water-level was lowered by 1 foot. For the safety of the banks along this portion some protective works were necessary; but the cost of these will be to some extent compensated, as the low-lying parts of Thun will in future be less exposed to inundation.

The employment of the Gumpenberg rollers was at first looked upon with distrust, as they had failed when used, although under totally different circumstances, in the improvement of the river Simme (a feeder of the lake of Thun). It was objected to them that they would only answer when always submerged, and that if alternately wet and dry they would soon rot and have to be replaced by stone. It was also urged that they would not resist a great velocity, but would break up and lie about in the stream and thus cause obstructions to the steady flow of the river. But after four years' experience the Author states that though in some cases they had, from the scour of the water, sunk down 8 feet, and had been displaced 30 feet laterally from their original position, yet in a length of 64,000 feet only four very trifling breaches had occurred. Other advantages, especially economy, are claimed for them. In rivers always charged with earthy deposit they act most beneficially, for the mud settles on them at the foot of the slopes, which in time extends to the banks and becomes self-planted. This, however, is not the case with the Aar, which flows out of the lake of Thun as a clear stream, and is only occasionally made muddy by the Zulg. Where the stream has a great fall, and therefore great velocity, and is heavily charged with coarse deposit (as in the case of the Zulg), these rollers should not be used. The foot of the slopes in that tributary is consequently protected, as before mentioned, by being laid on a wooden grillage bedded upon a foundation of rubble.

In the second section five rollers were used instead of three, because it was not possible to get all the stone for the revetment in time, and hence an efficient but speedy protection was necessary, which was successfully afforded by this means. The result of the work has been to give a uniform depth and fall, and therefore velocity, and no deposits of mud have been formed in the river.

W. H. E.

Regulation of the Danube at Vienna. Removal of the Old River Works at Nussdorf. By I. LEDERER.

(Allgemeine Bauzeitung, vol. xli., p. 74.)

The Author first gives an outline sketch of the early condition of the Danube in the locality specified, showing that in the beginning of the eighteenth century the main channel of the river ran along the left bank, which was much cut into and breached in consequence, islands and sandbanks being formed in the shallows on the right side. At this period a pool or backwater (the "Schwarze

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Lacke") extended along the left bank in the neighbourhood of Kahlenberg, swept past the village of Jedlesee, and rejoined the Floridsdorf branch of the river, but in 1848 this was shut off.

Between the years 1785 and 1816, nine large and several smaller works had been constructed with the object of turning the current from the left to the right side of the river, and preventing further breaching of the left bank. All these old river works had their foundations from 15 to 20 feet below zero of the gauge, and they varied much in character. Some consisted of simple "pierre-perdue" work, others of piles surrounding a core of rubble, others, again, of boxes filled with stone and protected by piling; while some were composed of cross layers of fascines, filled up with stone or rubble, sunken boats, piles and cross beams fastened together, &c.

A description of each work is given in the report, and its position is shown in a plate, which conveys a rough idea of its form as determined by soundings at different depths. The removal of these old works was undertaken by the contractors for the regulation of the Danube, under the direction of Herr Gustav Wex. The machinery employed consisted of the usual appliances, viz. dredgers or excavators, pile-drawing machines, &c., and for the transport and discharge of the material removed hopper barges and boats were used respectively. From thirty to one hundred men were employed in the removal of the old material, in addition to those required to manage and work the machinery.

According to the original project, in which the old works were to have been cleared away for a depth of 12 feet below zero, and where the breadth of the new cut was fixed at 1,037 feet, the quantity of material to be removed was estimated at 224,000 cubic yards below zero, 18,900 above zero, and 3,426 piles, but the depth of excavation was subsequently reduced, and hence the quantity of material to be removed was also diminished. The project also included the reclamation of a large quantity of land, the formation of an even bed for the river, and the permanent navigation of the Vienna Canal, which "takes off" from the river at Nussdorf.

The removal of the old works was commenced in September 1871, on what is called the "Schwarze Lacke" groyne (extending about 165 feet from the right bank of the river) and also on a neighbouring half-moon shaped work in the middle of the stream. Simultaneously, new head works were constructed for the canal. On the 5th of December following all the works had to be stopped in consequence of ice-drifts. Up to this time about 2,530 cubic yards above zero, 2,380 below zero, 269 piles and 1,313 lineal feet of cross beams and sleepers (*Schwellen*) had been removed.

In the following spring, when the ice had disappeared, work was resumed, the operations being commenced on another groyne lower down the river, but owing to the difficulties met with, little progress was made. Steam power was therefore substituted for manual labour in working the machinery. A new machine was specially constructed for drawing the piles, and a 25-HP. dredger

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or excavator was also set up. In September another dredger, of 18 HP., was added, but as it did not work satisfactorily, it was replaced by one of 25 HP., while the number of pile-drawing machines, &c., and the strength of the working party were increased; but owing to the difficulties encountered, and the damage done to the machinery, entailing loss of time in repairs, the works did not advance rapidly.

Being apprehensive of ice-drifts, sanction was obtained for the employment of one hundred extra sappers. A third dredger was also set up at the "Schwarze Lacke" groyne, but the difficulties seemed to increase.

The following table exhibits the monthly progress during 1872:—

Months.	Cubic Yards Old Masonry Work, &c., removed.	Number of Piles drawn.	Lineal Feet of Sleepers, Cross Beams, &c., removed.
April . . .	7,400	..	..
May . . .	26,224	40	..
June . . .	10,860	20	486
July . . .	9,180	166	1,094
August . . .	5,880	46	502
September . .	15,245	20	182
October . .	9,923	375	2,978
November . .	6,676	175	5,486

In the early part of December, the usual ice-drift being expected, works were stopped and the machinery, barges, &c., moved to a place of safety; but the winter of 1872–73 brought no ice.

Chief Engineer Lauer now resolved to use dynamite for blowing up the works on the right bank of the river; but the results not being satisfactory dynamite was abandoned, and recourse had to very powerful machinery. This worked from the 1st of March to the 10th of December, 1873, with good results; a strong ice-drift then occurred, which put a stop to all further operations till the 1st of March, 1874, when additional machinery was set up and the work pushed on with energy. By the end of November 1874 the whole of the old river works had been removed for depths varying from 6 to 12 feet below zero of the register. The removal of these old works at Nussdorf has been of great benefit to Vienna, by removing all danger from floods, &c.; for during a high flood in August 1874 the registered observations showed that the water in the Vienna Canal stood at 2 feet lower level than formerly. The current now sets again along the left bank, as was the case in the early part of the century. The cost of the work amounts to about £52,000.

W. H. E.

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Regulation of the North Elbe. By H. DALMANN.

(Deutsche Bauzeitung, vol. x., p. 455).

The Elbe, which connects Hamburg with the interior and with the sea, has only one channel till it enters the Hamburg territory. This was formerly a bay exposed to the tides; the silt deposited by the river gradually formed islands, dividing the mouth into numerous channels of continually varying depth, most of which have, in the course of time, become either naturally or artificially closed. Several of them, however, still remain, the most important being the North and South Elbe. The character of these two main streams is entirely different. At the bifurcation the South Elbe is the main channel, its depth and width exceeding that of the North Elbe both at mean and at high-water mark, and its fall at the upper part being less than that of the other. Opposite the town of Hamburg, however, it again divides into the South Elbe and the Reicherstieg, and at Moorburg into the old South Elbe and the Sandau, the latter again dividing below Altenwärder into various branches, the Köhlfleth, Köhlbrand, Mühlenfleth, &c. All these branches have naturally a far smaller volume of water than that brought down by the other arm, and the fall required to carry it off is therefore relatively greater.

On the other hand, the North Elbe, which is both narrow and shallow at its upper end, is greatly augmented by the addition of the Dove Elbe and the Reicherstieg, and its mouth is well situated for the admission of the tide. Still the flood tides arrive at the bifurcation of the two streams more quickly by the South Elbe, partly because it is shorter, and partly because the fall in the upper part of its course is less. Consequently the silting up of the northern arm steadily increased.

The Hanoverian authorities preceded those of Hamburg by closing the upper mouths of the most important secondary arms, so as to concentrate the water almost entirely in the Köhlbrand; and as far as the banks of the stream were in their territory, they made the channel of one uniform width.

The Hamburg authorities, on their part, narrowed the North Elbe by means of sheet piling (Stackbauten); in the lower part several branches between Reicherstieg and Köhlbrand were cut off, and the bed of the river was deepened by dredging; but, notwithstanding this, the volume of water became gradually less. As the depth of Hamburg harbour, and more especially in the roadstead, depends on the volume of water in the North Elbe, it was imperative that its condition should be improved. Herr Dalmann therefore prepared a plan which has since been strictly followed.

The main points of this plan are as follows:—Widening of the stream at all points where it has become too narrow, both at mean and at high-water mark; the removal, as far as possible, of the still existing bifurcations; improvement in the shape and width

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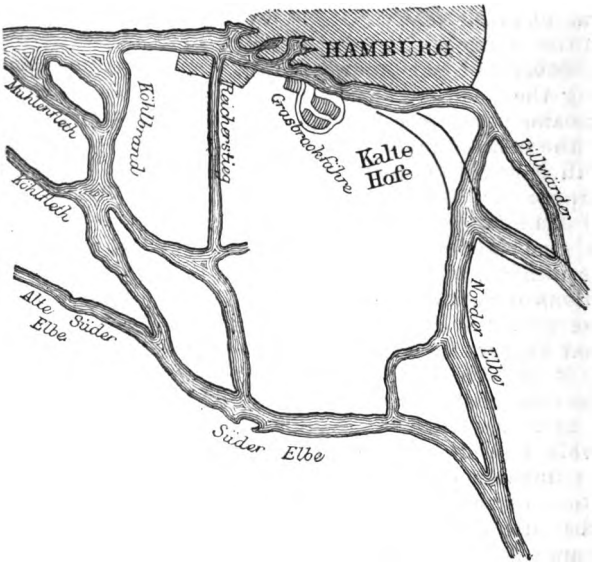
of the mouth by building; a cutting on one side, and an embankment on the opposite side of the undivided Elbe; shortening the channel by straightening its curves; but above all cutting off the concave at Billwärder by means of a canal through Kalte-Hofe. The tidal basins were to be separated and enlarged; the line of the banks kept by means of sheet piling, filled in behind with stones; the bed of the stream to be dredged, and the stream to be kept together at high water by the construction of guide dams.



A commencement was made by widening the narrowest parts. This was followed by the dredging and embanking of the parts between Rothenburgsort and Schumacherwärder (a distance of $1\frac{3}{4}$ mile), and between Buntehaus and Gamm-Elbe (a distance of 3 miles), carried out between 1863 and 1868. The improvement of the Köhlbrand commenced in 1869, and was finished in 1873. The most important piece of work, the cutting of Kalte-Hofe, is now in progress. The results hitherto obtained are satisfactory, as by the yearly gauging of the cubic contents of the channel, reduced to low-water mark, it was found that between 1857 and 1872 the percentage of increase was as follows:—

	Per cent.
From the old bifurcation to Gamm-Elbe	88·50
„ Gamm-Elbe to Rothenburgsort	26·50
„ Rothenburgsort to Grasbrookfähre	96·00
„ Grasbrookfähre to the old Köhlbrand point . . .	39·25

On the total length of the North Elbe from the upper to the lower point the increase was 56 per cent.

Thus from 1857 to 1872 the stream between Grasbrookfähre and

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Köhlbrand has increased in cubic capacity by 38,912,000 cubic feet, or from 99,050,000 cubic feet to 137,962,000. During this time 42,350,000 cubic feet of material have been removed by dredging, proving that unless improvement of the upper part had continued, Hamburg would not have been able, even with dredging, to achieve the gain of 39¼ per cent.

The part of the river where the cutting is being made is very unfavourably situated, as former works, now half decayed, rather obstruct the stream. Dredging has only been resorted to when it was absolutely necessary on account of the shipping; but the influence of the regulation above and below has increased the mean depth, and the volume of water passing through has augmented 26½ per cent. The improvements which had been effected, added to the observation that the point of union of the flood-wave which flowed through the North and South Elbe was almost at the mouth of the latter, so that the real point of separation of the two streams lay very close to the bifurcation of the channels, proved to the Author that if the regulation works were continued and fully carried out, the North Elbe would cease to be dependent on the Southern, notwithstanding the difference in length and the naturally unfavourable state of the upper portion of the former, which could not be entirely changed.

On comparing the breadth and length of the two arms of the stream, it is seen that in the upper part of their channels the width of the South Elbe is considerably greater than that of the North, both at mean and at high-water mark, which it would be impossible to alter without destroying the existing arrangements. Farther down stream the breadth of the North Elbe continually increases till it arrives at its lower mouth, which opens widely into the main stream; whilst the South Elbe, and its chief arm, the Köhlbrand, vary in width. At the Wattershof the width of the South Elbe is only 440 feet at the ordinary water-level, and 650 feet at the highest flood-water mark. The North Elbe is 12 per cent. longer than the South Elbe, and though this difference cannot be entirely removed, the cutting at Kalte-Hofe when completed will reduce it to only 5½ per cent.

On the completion of the whole of the correction works, the North Elbe at 3½ miles from its commencement will have a width of from 600 feet to 650 feet. At its juncture with the Dove-Elbe its width becomes from 750 to 770 feet. Where the lower Dove-Elbe enters its channel it becomes 820 feet wide, increasing to 890 feet. It continues increasing until, at 9½ miles from the commencement, where it is joined by the Köhlbrand, its breadth is 1,280 feet.

The cutting at Kalte-Hofe was commenced in April 1876, at the lower end, by the construction of a protecting dam on the foreland close to the banks of the stream. The whole cutting will be completed in 1877, as far as the upper dam of Kalte-Hofe, and in 1878 the water will be admitted. When the stream flows freely through the new channel, the present course will be closed

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by fascine work and stones; and, lastly, a guide dam for high water must be made in the present bed of the Elbe. The whole work is expected to be finished in the course of 1878. The breadth of the new dam at the summit is 11 feet 6 inches, the exterior batter 1 in 3, the interior 1 in 2½.

The locomotives for the spoil transport are from 40 to 60 HP., and draw twenty to twenty-eight wagons containing 52 cubic feet each. The total cost of these works, exclusive of compensation for land and the outlay for dredging, is estimated to be:

	£.
Earthworks for cutting at Kalte-Hofe . .	113,520
Fascine work and stones for ditto . . .	13,560
Earthwork for cutting at Billwärder island.	35,460
Fascine work and stones for ditto . . .	5,040
Total	167,580

The total cost of the correction works in the North Elbe from 1857 to 1872, including dredging, amounted to £219,223 12*s*. The contractors are Messrs. Schmidt and Bichel.

W. W. W.

On the Blasting of Ice.

(Engineering News, Chicago, vol. iv., p. 12.)

During the winter of 1874–75, ice formed to an extraordinary thickness in all the streams of the west, and apprehension was felt towards spring that the breaking ice would sweep away the bridges. The most exposed structure on the Illinois Central railroad was the bridge over the Kankakee river, consisting of a Bollman iron truss, of three spans of 170 feet each, and two spans of 60 feet each. About 100 feet below the bridge there is a dam, and during the winter the water stood about 3 feet below its top. It was thought advisable to break up the ice above the bridge as soon as the water should rise sufficiently to flow over the dam, so that it might pass between the piers in small masses. On the 22nd of February, 1875, men were set to cut the ice near the bridge into cakes 15 feet square. A waterproof fuse 16 feet long was inserted, carefully packed with putty, into a 6-lb. can of rifle powder, securely fastened to the end of a scantling 12 feet long, and the fuse was attached by twine to the scantling. A hole, of sufficient size to allow the can and attachment to be put through, was cut in the ice, and the can was pushed under, 12 feet beyond the hole, the ice being 26 inches thick. The result of each explosion was to break into small pieces a portion of the ice field, about 15 feet in diameter, and to visibly crack the ice below its surface, in several places, for a distance of 20 feet beyond the centre.

Further blasting being necessary, a number of ordinary 1-quart

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oyster cans, filled with 1¾ lb. of sporting powder, were exploded, and broke up the ice for about 30 feet all round, throwing out cracks for 30 to 40 feet or more. The greatest execution was done with blasts in the unbroken ice field. A charge of 1 lb. of powder did not fracture the ice. A 6¼-lb. can of Dupont's sporting powder opened a hole 30 feet in diameter, and threw many pieces of ice, several feet square, perpendicularly into the air, probably to a height of 150 feet, the fragments falling within a radius of 100 feet. The seams in the ice, however, were not opened to any greater distance than in the 1¾-lb. charge. Ordinary blasting powder was tried, but without breaking through the ice. A charge of 19 lbs. had the effect of raising the whole mass of ice, extending across the river, several inches without producing a fracture. A similar charge, exploded 6 feet below the surface, had no immediate perceptible effect, but for a distance of 500 or 600 feet up the river the ice appeared to be seamed with cracks and ready to go to pieces. When the ice broke up in consequence of the thaw, it drifted down mostly in the cakes as cut, and whenever there was a disposition to gorge, one or two blasts kept it in motion. In March 1875 Col. F. U. Farquhar, U.S.E., was obliged to blast ice 5 feet thick, in order to set free a turbine wheel. After some work with picks and axes, a ½-lb. dynamite cartridge, with a Brown's exploder attached, was fastened to a pole about 10 feet long, and pushed up under the ice as far as the stick would allow, and exploded. No hole was made through, but for a space about 10 to 12 feet in diameter the ice was broken up so as to be easily removed with pike poles.

J. D. L.

The Mérienne Dam on the Charente. By M. ALEXANDRE.

(Annales des Ponts et Chaussées, 1876, p. 574, 1 pl.)

A movable dam has been erected at Mérienne across the Charenton, a branch of the Charente, in order that during the summer the waters, which flowed through this channel, may be diverted into the main river, for the sake of the navigation and the factories.

The difference of level between low and flood water being about 10 feet 8 inches, in order to reduce the height of the framework of the sluices, shuttles were adopted, which, by omitting the upper portion of the outer cheeks of the grooves in which they slide, and by hinging their connection with the racks, are able, when lifted, to rise by the pressure of the flood-waters towards a horizontal position, sinking again to a vertical position when the flood has abated. The cast-iron uprights forming the frames for the shuttles, each weighing nearly 6 cwt., have brackets supporting a footway along the dam; they are joined at the top by cast-iron beams carrying the gearing for working the racks; they are

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bedded in and bolted to a stone apron, set in cement, 6½ feet wide and 18 inches thick, with its upper surface at ordinary low-water level, and resting on a foundation of piles, connected together by a framework of cross timbers. The portions of the piles above the bed of the river are buried in a mass of rubble stone, and the spaces between the cross timbers are filled with concrete. There are nineteen sluice-ways, of which seven are between the two piers of masonry in the water-way, and six between each pier and the adjoining side wall; they are closed with oak shuttles, each 3 feet 11 inches wide, 4 feet 5 inches high, and 2 inches thick. The ordinary fall over the dam is 4 feet 5 inches, but it attains 5 feet 3 inches in floods. The total cost of the work was £596, or about £8 10*s.* per lineal foot of sluice-way. The foundations and apron were completed in three months in 1874, and the iron superstructure was erected in 1875 in less than a month.

L. V. H.

The Gileppe Dam. By M. BODSON, E. DETIENNE, and F. LECLERCQ.

(Annuaire de l'Association des Ingénieurs de Liége, 2nd series, vol. v., p. 281, and vol. vi., pp. 268 and 421, 14 pl.)

The important cloth manufactories at Verviers require a large supply of pure water, formerly obtained from the Vesdre; the extension of the manufactories rendered that source insufficient, and returned the water to the river in such a polluted condition that it destroyed the fish, and brought malaria to the towns lower down stream. Accordingly the inhabitants of Verviers determined to obtain a new water supply; and the design of a scheme for utilising the Gileppe, intrusted in 1857 to M. Bidaut, was, after various delays, submitted, in 1868, to the Minister of Public Works.

It was determined, in addition to supplying the river Vesdre with 3,924,000 cubic yards of water in the year for maintaining its low-water level, to provide the manufactories with a water supply of 19,097,000 cubic yards a year, or 8,808,000 gallons a day. The carefully measured discharge of the Gileppe, amounting to 30,480,000 cubic yards in the year ending September 1864, and to 25,910,000 cubic yards in the year ending September 1865 (an unusually dry year), was considered sufficient, and it was thought that a proper supply in times of drought could be insured by providing a storage reservoir having a capacity of 15,700,000 cubic yards. It was found that such a reservoir could be formed by either making four dams across the Gileppe valley each 95 feet high, or a single dam 147 feet 8 inches high. The latter plan was adopted as being in all respects preferable in execution, and the sole objection that could be urged against it, namely, the terrible consequences of a failure in the dam, was removed by making it

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exceptionally strong. The height proposed, moreover, was not without precedent, as the Alicante dam, nearly three centuries old, is 134½ feet high; and that at Furens, recently constructed, is 170 feet high.[1] The site selected for the dam was a narrow part of the valley where the strata were most uniform and compact. The reservoir above it when full covers 198 acres, and has a capacity of 16,010,000 cubic yards. The dam is in the form of an arc of a circle of 1,640-feet radius; its total height is 154¼ feet; its length at the top is 771 feet, and at the base, 269 feet; it is 49¼ feet broad at the top, and 216 feet at the base. The foundations were carried down not less than 3¼ feet into the solid rock, all loose material having been removed, and the ends were carried up in steps in the rock forming the slopes of the valley; the foundations were laid horizontal throughout, and were carried down an additional depth at three places in the section, and at the faces of the dam throughout its length, so as to provide against the infiltration of water between the rock and the masonry. The batter of the upper face of the dam is ¼ to 1, and of the lower face 1 to 1, up to 34½ feet from the top, where the batter of the upper face changes to 1 in 10, and of the lower face to 1 in 2·86, and these batters are continued up to the top. The dam is built of stone set in hydraulic mortar, coursed and rubble masonry being employed for the main portion, pick-dressed masonry for the faces, and ashlar masonry at the footings of the faces and at the angles where the batter changes. The total amount of masonry forming the dam is 325,000 cubic yards. There are two weirs, 6 feet 7 inches below the top of the dam and 82 feet wide, situated one at each extremity of the dam, for letting the flood waters of the Gileppe escape, and to prevent the water ever reaching the summit of the dam. Before the dam was commenced two subterranean channels were excavated in the slopes of the valley, one on each side of the site, and 328 feet from it at the nearest point, for conveying the water supply from the reservoir: they proved of great value during construction by conveying away the waters of the Gileppe, thus enabling the dam to be built up solid at once. The sectional area of each channel is 64 square feet, which, with a head of 13 feet, would suffice for the discharge through the two of 11,000 gallons per second, which is the greatest discharge of the Gileppe. The channels are lined throughout, the arch-work being of brick 1·4 inch thick, and the piers of masonry 1 foot thick. Two wells, each 9 feet 10 inches in diameter, and lined with masonry 1 foot 8 inches thick, go down from the surface to the subterranean channels: in the first instance they served as shafts during the driving of the tunnels, and are now used as a means of access to the paddles controlling the water supply. The water is conveyed from the reservoir, through the channels, in cast-iron pipes, as the water has to rise 23 feet 9 inches to reach the level of the sill of the aqueduct. The aqueduct crosses

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xli., p. 244.

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the Borchène valley, and terminates, near Verviers, in a distributing tank from whence the conduits branch off for supplying the town. The Authors give full details of the works and machinery connected with the water supply.

In comparing the Gileppe dam with the Alicante dam, which has a breadth of 111½ feet at the base and 65½ feet at the top, and with the Furens dam, which has a breadth of 164 feet at the base and only 16½ feet at the top, it appears that the Gileppe dam is broader at the base than either of the others, and broader at the top than the Furens dam.

The large breadth was adopted in consequence of the volume of water retained by the Gileppe dam being over four times that retained by the Alicante dam, and more than six times the amount retained by the Furens dam, so that a failure in the Gileppe dam would be attended by far the most disastrous results. The Gileppe dam is also much longer than the other two.

In calculating the proper theoretical dimensions of the breadth of a dam the following equation is obtained for the curve of the profile:—

$$y = 166{\cdot}215 \log \frac{x}{3{\cdot}28}.$$

The theoretical section of any dam may be represented graphically by tracing the curve represented by the above equation: the axis of y, to which the curve is referred, forms one of the faces of the dam, and making the top of the dam coincide with the point where a line, being both a tangent to the curve and inclined at an angle of 35° to the axis of y, cuts that axis; the other face of the dam is represented by this tangent line from the top down to the point where it touches the curve, and by the curve itself below this point. The Furens dam agrees approximately with the theoretical section thus obtained; the Alicante dam nearly coincides with it at the base, but is much too broad as it rises. The Gileppe dam is broader than the theoretical section throughout, but it was purposely made exceptionally strong, and the top was made broad enough to form a carriage-way with footpaths, and also to admit of its being raised 33 feet, in which case it would nearly be the theoretical width at the base. The theoretical width at the top is zero, but in practice it should not be made less than 6½ feet.

The dam was built by MM. Braive and Caillet; the first contract was let in April 1869, the tunnels and wells having been commenced in February 1867, and the work was completed by November 1875. It was made at the cost of the State, which expended £182,000 on it. The people of Verviers had to bear the expense of the works connected with the water supply, receiving a grant from the State of £8,000 in consideration of the portion of water they supply to the Vesdre.

L. V. H.

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Rhone Irrigation Canal. By F. VIDALIN.

(Revue des Deux Mondes, vol. xix., p. 920.)

The Author here gives an account of the increasing and disastrous losses which have now for some years been experienced by the cultivators of the valley of the Rhone; and of the works intended both for the irrigation of a large area of the basin of that river, and for the supply of water to the towns of Valence and Montélimart, the scheme for which, worked out for several years by M. A. Dumont, Chief-Engineer of the Ponts et Chaussées, has received the approval of the Council of State, and is about to be submitted to the Chamber of Deputies. The main cultivation of the Rhone valley has of late years been divided between the growth of the mulberry, of the vine, and of the madder plant. The pebrine, a disease which has for many years affected the silk worm, in 1876 almost entirely destroyed the crop of silk. The vine suffers from the ravages of the *Phylloxera vastator*, which is only partially checked by the application of sulphur, but which can be effectually destroyed by submerging the vines during the winter. In addition, therefore, to the usual functions of a canal of irrigation, it is proposed to employ the water brought down by the Rhone Canal for the submergence of the vineyards of the district during the winter season.

The point of derivation of the canal is situated a little below the town of Vienne, near the rocks of Condrieu. The project contemplates the supply of about 1,000 feet per second to be here taken from the Rhone; and an equal quantity is to be supplied by the interception of the affluents which cross the line of the new channel. This line follows the undulations of the country, falling at a regular grade of 1 in 4,166. As the fall of the river itself is much more rapid, the canal gradually runs at a higher and higher level, as compared with the bed of the river.[1] It thus passes above Valence and Montélimart; which towns it is intended to supply with a constant service by gravitation. As the main object of the work is the restoration of the fertility of the vineyards of the Gard, the Hérault, and the Aude, the canal is to cross the bed of the Rhone from the left to the right bank, at the constriction of the valley, which occurs near Mornas, a little above Pont-Saint-Esprit. A large reservoir is here to be formed at a spot where the left bank rises in a cliff to the height of 230 feet. The water is

[1] M. Vidalin does not give the fall of the Rhone. In the "Edinburgh Review," No. 297, p. 108, this is given as follows. From Bellegarde to Lyons, 1·009 mètre per kilomètre, or a little over 1 in 1,000. From Lyons to Beaucaire the inclination varies from 0·5 mètre to 0·3 mètre per kilomètre, or from 1 in 2,000 to 1 in 3,333. The velocity of the river in that part of its course is from 5 to 8·2 feet per second. Between Beaucaire and Arles the inclination is reduced to 1 in 8,000.—F. R. C.

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led hence through wrought-iron pipes, which are to be carried on a bridge over the river, and ascend the opposite side of the valley as a siphon, emptying into a second reservoir. This siphon, which will be nearly 2 miles long, is the most important work of art in the whole scheme. M. Dumont, the Engineer, estimates the cost at £280,000. In a report made, in 1871, to a commission appointed by the National Assembly to study the improvement of the communications of France, M. Krantz proposed that the passage of the Rhone should be avoided by bringing the canal along the right bank from the point of derivation. But, following the survey made under the restoration by the eminent engineer, Cavenne, M. Dumont has considered the course by the left bank to be preferable, even though involving the cost of the siphon at Mornas. The Council General of the Ponts et Chaussées approved this choice, which allows the use of a part of the canal for direct communication with Marseilles. On leaving the reservoir into which the siphon discharges its water, the canal curves towards the coast of the Mediterranean, which it finally reaches after passing near the most important centres of population in the south of France, namely, Nîmes, Lunel, Montpellier, Béziers, and Narbonne. In a course of above 300 miles the canal commands an area of 540,000 acres which may be irrigated by its water, and it accommodates centres of population containing altogether more than five hundred thousand inhabitants.

The price of irrigation is the same for both a summer and a winter supply, being fixed at a little over £1 per acre. Applications have already been made for the water by the proprietors of more than 32,000 acres; and twenty-four syndicates have been formed, in the six departments of the Isère, the Drôme, the Vaucluse, the Gard, the Hérault, and the Aude, which have taken charge of the distribution of the water to be delivered by the canal. The projectors cite the examples of the Canal Cavour, in the valley of the Po, and of the Ganges Canal in the North-western Provinces of India, as conclusive as to the remunerative nature of their undertakings. The Cavour Canal[1] draws from the Po a supply of upwards of 3,888 feet per second, to water the plains of Verceil and of Novara, before it falls into the Ticino. This canal was designed, authorized, and executed in three years. The Rhone Canal has been an object of desire for the inhabitants of six departments of France for more than twenty years. The charge for irrigation on the Cavour Canal is £1 4*s*. per acre. The land to which ordinary cultivation is applicable in the six departments already named lets at a rental of about £1 per acre, while the small area which is now irrigable is eagerly sought for at from three to four times that rent. It is thus concluded that the charge proposed for the water of the Rhone Canal is moderate.

The delivery of the canal is estimated at 930,000,000 metric tons during the summer season, or between the 15th of April and the 15th

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlvi., p. 292.

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of September; and at 700,000,000 metric tons between the 15th of September and the 15th of April. The supply is more in summer than in winter, in consequence of the melting of the snows in the former season. The month of closure, which is regarded as necessary for the annual repairs and cleaning of the canal, is therefore fixed for the winter. Two-thirds of the volume of water are considered to be applicable to irrigation, one-sixth is destined for the domestic supply of the towns, and the remaining sixth is allowed for evaporation and waste.

It is considered in the Rhone valley that a stratum of water 39·38 inches deep, divided into twenty periods of supply of about one week apart, or 1·969 inch per week for twenty successive weeks, is sufficient for ordinary cultivation during the summer. This quantity is equivalent to about 4,000 tons per acre. The Council General of Ponts et Chaussées have taken the somewhat higher rate of 6,000 tons per acre as the supply required during a summer season of one hundred and eighty days.[1] At this rate only about 100,000 acres, or less than a fifth of the area commanded by the canal, would be watered. The question, therefore, arises as to increasing the capacity of the canal. The average flow of the Rhone (M. Vidalin omits to mention at what point in its course) is more than 14,000 cubic feet per second; and the same quantity that is taken from the Po by the Cavour Canal could easily be spared, without mischief, by the Rhone.

The available winter supply of the canal, amounting to about 6,000,000 metric tons, is destined to effect the submersion of the vineyards. According to experiments of M. Faucon 23·6 inches of water, supplied gradually, is enough to submerge a vine for a month. This demands 2,360 metric tons of water per acre. It is considered that it will be prudent to provide for a larger supply, in order to insure the complete destruction of the *Phylloxera*.

In addition to the value of water as a source of supply to vegetable and animal life, M. Vidalin calls attention to the motive power derivable from a current running for 300 miles at a mean elevation of 164 feet above the bed of the river below, which is stated to be more than 5,000 HP. The ordinary cost of motive power per HP. in France is stated at £20 per annum. It is proposed to let the water power of the Rhone Canal, on terms of subscription for fifty years, at £8 per HP. per annum, the power being measured by the fall of 22 gallons per second, for 39·38 inches. The canal skirts the course of the railway from Lyons to Marseilles for 86 miles; and it is suggested that factories moved by water power may thus be established in the neighbourhood of the stations. Further, between the rocks of Condrieu and Mornas it is expected that the canal, which will be 49 feet

[1] This supply gives the same number of metric tons per acre as that which is allotted, in cubic yards, to the irrigation of an acre of rice on the Madras Irrigation Canal.—F. R. C.

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wide and 9·8 feet deep, can be utilised as a navigable highway, as is the case with many of the most important irrigation canals of modern times.

The annual loss now suffered by the industries of the Rhone valley has been estimated at £3,200,000. The sum estimated as necessary to complete the entire network of the proposed canal is £4,800,000. The local interests ask for the aid of the State to the extent of one-third of the cost of the main line of canal alone, which third would amount to £1,200,000. It is proposed that this sum should be raised by the Government by the issue of annuities of £54,000 per annum, which at the rate 4½ per cent. for ninety years would cover the amount. The remainder of the Paper is occupied by remarks on the difficulties opposed to navigation by the rapid current of the Rhone, and on the facilities that would be offered for transport by the canal from the basin at Mornas to the point of derivation near Condrieu.

F. R. C.

The Reservoirs of the Rio Rimac, Peru.

(Annales des Ponts et Chaussées, 1877, p. 215.)

These reservoirs have been so constructed as to make use of nine lakes, situated at altitudes of from 14,065 to 15,968 feet above the sea-level; notwithstanding this great elevation, the climate is not severe, and the lakes are never frozen over. The fine season lasts five months, viz. from April to September, but is generally unfavourable for masonry work in consequence of the frequent frosts; during the remainder of the year rain, snow, and thunderstorms are encountered. The prevalence of earthquake shocks, together with the unfavourable conditions of climate, and the great risk to the town of Lima, situated at no great distance in the valley below, caused the abandonment of the masonry dams originally projected. Further examination of the ground showed that the lakes were sufficiently deep to be utilised without artificially raising their natural banks. In order to render the water of these lakes available for use, deep, narrow trenches were carried down through their banks, to be afterwards closed with an iron dam bedded in masonry and provided with sluices. The end pillars of the dam were built into the rock at the sides of the cutting, and the intermediate pillars, dividing the dam into panels 9 feet 10 inches in width, were built of masonry of a thickness in the direction of the length of the trench equal to about six-tenths of the head of water, the thickness at the top being 4 feet 11 inches. The panels consisted of plates $\frac{11}{16}$ inch in thickness, by 9 feet 10 inches by 1 foot 3 inches, supported by double ⊤ iron beams 9 feet 10 inches in length, placed

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horizontally 1 foot 3 inches from centre to centre, the joints were secured by a layer of felt and bolted to a cover-plate. The total width of dam amounts in two cases to 168 feet and 152 feet, with a height in the centre of 19 feet 8 inches, and 16 feet. The following table gives the head of water in the different reservoirs, and the amount impounded :—

	Head in Feet.	Cubic Feet of Water available.
Pirhua	16·4	17,481,000
Manca	34·45	36,022,000
Huachua	13·78	38,600,000
Puiro	34·45	61,167,000
Misa	16·40	21,683,000
Huasca	21·32	190,421,000
Carpa	52·49	737,952,000
Quisha	54·13	350,365,000
Sacra	..	200,233,000

A. T. A.

Memorandum on the Irrigation Duty of Water, and the Principles on which its Increase depends.

By J. S. Beresford, Executive Engineer.

(Professional Papers on Indian Engineering, 2nd series, vol. v., p. 408.)

From detailed observations on the depth of moistened soil, the Author thinks it may be fairly concluded that 4 inches depth of water is ample for one watering, and if more is given it collects in hollows and soaks the ground to an unnecessary depth, or is evaporated.

The theoretical duty of water running at the rate of 1 cubic foot per second, for a month, is 180 acres, and this is nearly correct for the dry months of April, May, and June, the kharif season of high demand. In the rabi, the theoretical duty per cubic foot, allowing for lighter watering, ought to be 320 acres, or the theoretical duty of water in such divisions as the Aligarh and Etawah ought to be 500 acres per year. But the actual duty obtained, even in the best divisions, is not over 160 to 180 acres, or about one-third of the assumed theoretical duty.

Calling D' the theoretical duty of a cubic foot of water, delivered at canal head, its actual duty D for the whole canal may be expressed as follows :—

$$D = C^{GC} \times D' . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where C^{GC} is the mean efficiency of the Ganges canal. Taking 500 acres as the theoretical duty, that of the canal for 1873–74 was 0·31.

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It is obvious that—

$$C^{GC} = C^{MC} \times C^{D} \times C^{W} \times C^{C} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where—

C^{MC} is mean efficiency of main canal;
C^{D} „ „ „ distributaries;
C^{W} „ „ „ village watercourses;
C^{C} „ „ „ the cultivators;
C^{MC} has been well known for years, and for 1873–74 was $\frac{155}{189} = 0{\cdot}82$.

As regards water entering the distributary head, the mean efficiency of a distributary system, including all parts, is the product of the last three factors given in equation (2), and from observations in the dry division of the Anupshahr Branch, with 500 acres as theoretical duty, is as low as 0·25 and 0·20.

Equations (3) and (4) are similar to (1) and (2), and express the same relations only for distributary systems:—

$$D = C \times D^{t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$
$$C = C^{d} \times C^{w} \times C^{c} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Where C is the efficiency of water entering a distributary head to water a certain field from a certain outlet, D the duty of the water in this field, C^{d} the efficiency of the distributary between the head and particular outlet, C^{w} the efficiency of the particular watercourse between the outlet and the field, and C^{c} the efficiency of the particular cultivator who waters the field. The loss from evaporation is of little consequence as far as the channels are concerned, even in the hottest weather, and may be neglected; in the rabi season, roughly, 5 per cent. of probable discharge is considered by the Author a maximum. The chief part of the loss must therefore be due to percolation and absorption.

The Author explains minutely the combined phenomena of percolation and absorption,[1] and shows by diagrams the effect of gravity in elongating downwards the supposed cylindric surfaces due to absorption. The water, in short, has to follow the resultant of two forces—uniform attraction in radial, and gravity in vertical, directions.

It is pointed out in the course of this investigation, that, in the case of embankments, absorption ceases when the absorbing medium is limited. Assuming that absorption varies as the wetted perimeter, and that the wetted perimeter varies indirectly as some function of the length, or, in other words, that the total loss up to any point is the loss in the first mile, multiplied by some function of the length.

This function may be written L^{x}, where L is the length in miles,

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxix., p. 1.

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and x an index usually less than unity, and found by the Author in several cases to be $\frac{2}{3}$. If W is total waste down to any outlet, Q the discharge of rajbaha at the head, and C^{do} the efficiency of the rajbaha at that point, then

$$C^{do} = \frac{Q - W}{Q} = 1 - \frac{W}{Q} \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

but it has been pointed out that

$$W = AP \times L^x \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

and substituting this in equation (5),

$$C^{do} = 1 - \frac{AP \times L^x}{Q} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6a)$$

Where Q is the discharge of distributary at head, AP the ascertained loss by absorption and percolation in the first mile.

A similar expression to equation (6*a*) may be written for the watercourses:

$$C^w = 1 - \frac{ap \times l^x}{q} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Applying these equations to an *ordinary* case, let

Q = 50 cub. ft.; L = 10 miles; AP = 1·25 cub. ft. per mile; and X = $\frac{5}{6}$ths.

Also,

q = 1 cub. ft.; l = 6 furlongs; and ap = 0·03 cub. ft. per furlong.

Then,

C^{do} = 0·829	C^w = 0·820
C^o = say 0·750	C = 0·530

During the last twenty years no advance has been made in laying down and maintaining distributaries, and generally they are of an unnecessary length and faulty construction.

From the sand being dropped soonest the silt berm is not watertight near the head of a distributary, also the deposit on the bed is porous much further down stream than the sides. Hence it is recommended that the sides be puddled only in the first 5 miles, but the bed everywhere to a thickness of 6 inches. The Author also recommends strongly the puddling of village watercourses, especially over sandy ground. A layer of puddle 3 inches thick, and covered with 9 inches of earth to protect it, would suffice, and cost from 150 to 200 rup. per mile, including the necessary masonry in sections and bed levels.

J. C. I.

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Hydraulic Experiments at Roorkee, 1875–76.

Abstract ad-interim Report by Capt. ALLAN CUNNINGHAM, R.E.

(Professional Papers on Indian Engineering, 2nd series, vol. vi.)

The following are the leading conclusions arrived at by Captain Cunningham since the date of his first report, an abstract of which has already been given.[1]

In a rectangular channel the mean velocity in a vertical plane at and near the centre is found to be nearly the same as the mid-depth velocity. Measurements of sub-surface velocities by means of a ball and surface float are liable to errors due to the surface action on the attached float, and it is found that a "rod," reaching nearly to the bottom, is probably as true a measure of the mean velocity through its plane of motion as can be obtained. The line of maximum velocity is usually below the surface; it is highest at the centre, and gradually sinks towards the margin, being at about mid-depth near the margins, hence the mid-depth velocity differs from the mean velocity very considerably towards the margins. The mean velocity of a whole section is not simply proportional to $\sqrt{RS}$, but if it be assumed that $u = C\sqrt{RS}$, C must be a factor increasing with R.

No marked diminution of the mean velocity was observed over about seven-eighths of the width of the rectangular channel of the Solani Aqueduct, and even close to the margin the decrease was only about one-sixth; on the other hand, in a trapezoidal channel the diminution of the mean velocity near the margin amounts sometimes to two-thirds of the central mean velocity.

B. B.

On the Laying of Subaqueous Mains of the Regensburg (Ratisbon) Waterworks across the Danube and the Regen. By A. THIEME.

(Deutsche Bauzeitung, vol. xi., pp. 2 and 21.)

The town of Regensburg is situated on the right bank of the Danube, a little above the mouth of the Regen, and on the opposite side to it. The source of its water supply being 3 miles distant, on the left bank of the Regen, the conduit conveying the water to the town has to cross both these rivers. Bridges exist at Regensburg and at Reinhausen, but at the time of the construction of the waterworks they were found unsuitable for carrying the main, as a winding course would have been necessary, which did not allow of the lateral expansion caused by variation in temperature.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xliv., p. 263.

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The main, moreover, had to pass through a reservoir on the summit of a hill, 150 feet high, between the wells and the town, and as the proposed deviation over the bridges would have made a difference in cost of £1,600, an almost straight course was adopted, and the passage of the rivers effected by subaqueous conduits.

Works of a similar nature had been carried out before at Bâle-on the Rhine, but under more favourable local circumstances. There, a light temporary timber bridge or staging having been erected across the river at the site of the main, and a trench 4 feet deep having been dredged by hand, the whole length of immersed conduit was first joined together on the bridge, and then let down by means of cranes into its place. In other cases this joining of the parts to be immersed had been effected on one of the banks previous to being floated into position by means of barges. In the present instance, however, these methods could not be adopted on account of the great widths of the rivers—the Regen being 315 feet wide at the crossing place, the left arm of the Danube 230 feet, and the right arm 407 feet. In the right arm of the Danube the depth of channel is 8 feet 3 inches, and the current 5 feet per second, while the nature of the bottom is in most places so soft that the trench had to be at least 8 feet 3 inches deep, with a slope of 5 to 1.

It was hence resolved to lay the main, with the assistance of a diver, in short pieces of two, three, or at the utmost, four lengths of pipe of 10 feet each. The trench was excavated by an ordinary steam dredger, and the greater part of the soil dredged had to be taken on shore. To effect this, when near the banks, the rail track of the shore was prolonged on pontoons into the river, and the earth wagons were brought direct under the shoot of the dredger. When in mid-river the soil was thrown into a barge alongside the dredger. The barge was held on by a long rope to a point of the shore slightly up-stream, so that when freed from its attachments to the dredger the force of the current drove it on to the shore.

Beginning near the shore, 30 feet of trench were dredged ready to receive the pipes, and two lengths of these joined together on a pair of coupled boats were let down into their place by tackles. The ends of this first set were temporarily closed by plates bolted on to their flange—the one on the shore side allowed the passage of a strong india-rubber hose, in communication with a hydraulic press. This arrangement permitted the testing of the pipes and their joints when in place. The pressure to which they were submitted was 12 atmospheres, the pipes having been tested beforehand at the works to a pressure of 20 atmospheres. The whole of the main was laid in a similar manner. The work of the diver consisted in removing the plate which closed the river end of the laid portion; guiding the next pair of pipes into position; ascertaining their exact bearing in accordance with the plans; joining them with the part already laid, and watching the filling of the trench so that the pipes should not be disturbed by it.

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The joining under water presented no difficulty, as it was done simply by putting in a few bolts, the joint being an ordinary flange-joint with canvas packing.

The Author describes at length the difficulties encountered during the progress of the works. They were all of a local character, and cannot be attributed to a fault in the method. Thus whilst crossing the main branch of the Danube, the waters rose five times to flood-level, and when near one of its shores, the trench suddenly struck on dolomite rock. In the left arm of the Danube and in the Regen the laying progressed regularly, and took in the first case from June 23rd to August 2nd, 1874, and in the second case from October 7th to November 28th.

A. O. B.

The Brussels Gas Works. By P. JULIEN.

(Annales industrielles, 21 Jan., 4 Feb., 1877, pp. 80 & 135, pl. 7, 8, 9, 10, 11, 12.)

The works here described are situated at Laeken, near Brussels; and, although not quite complete, have been in regular work since August 1875. They were constructed from the designs, and under the direction, of M. Somzée, and produce about 4,589,000 cubic feet of gas per twenty-four hours, supplying the whole of Brussels. The retort-houses, four in number, are parallel with each other, and occupy four out of eight spaces set out for that purpose. Between each house and outside the two end ones is a space for coal, affording room altogether for 9,800 tons. Each house contains two groups of sixteen beds of retorts, or a total of one hundred and twenty-eight, heating seven retorts each; or a total of eight hundred and ninety-six retorts, all of fire-clay, placed end to end, and each set of seven holding a charge of 2,640 lbs. They are heated by coke, but are arranged so as to admit the use of tar or naphthaline; and can also be worked on the Boëtius' system, to heat by "gazogène," and to use heated air for combustion. The arched roof of the furnace and retort chambers is constructed of hollow fire-bricks, forming an air space to prevent the dissipation of heat.

The ascension pipes from the retorts are connected to the horizontal receiving main by rectangular bends, so that all pipes are easily accessible for cleaning by coverlets. The hydraulic main is of a D form, with the flat side vertical, and the connecting pipe between each D entering at the upper part thereof, so that the tar, &c., collecting at the lower part of the D is easily drawn off without interfering with the working.

The coal used is from five mines of the Borinage, four of the Basin of the Ruhr, and two English; the annual consumption being about 98,000 tons. From each hydraulic main the gas passes through a series of condensing pipes 15·75 inches in diameter, and 492 feet in length, for each group of furnaces. From thence

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the gas passes through cascade scrubbers, of which there are sixteen, 8·2 feet in diameter and 36 feet high, and worked in pairs. From thence the gas passes to a large collecting scrubber 19·7 feet in diameter and 78·8 feet in height. The gas arrives at the centre of the base of each scrubber, and passes over and under flat discs held between pairs of hollow opposed discs kept cool by surrounding water; after traversing these the gas passes through four layers of coke kept continually damp by descending sprays of water from a cistern at the top of the structure. The scrubber cylinders, of sheet iron riveted together, are provided with doors for renewal of the coke; the whole being surmounted by an ornamental wood cover and roof. The passage of the gas through the large scrubber, is regulated by the purity of the gas after its exit from the others, the deposition of the naphthaline being facilitated by a jet of steam. The total surface for condensation, including the condensing pipes on the retort-house walls, is nearly 15 square feet per 1,000 cubic feet (50 square mètres per 1,000 cubic mètres) of gas per twenty-four hours. From the scrubbers the gas is drawn by two of Schmitz's exhausters, supplemented by one on Koerting's jet system, arranged so that the gas may be delivered into the gasholder or into the town mains. From the exhausters the gas passes through the purifiers, of which there are twenty-four, disposed in two parallel ranges in a special building provided with a steam traveller. The purifiers (which are worked in sets of three) have the ordinary external case and water-jointed cover, but, in addition they have an internal frame which supports the trays. When it is desired to change a purifier, these frames are lifted out, with their trays, and the whole is transported by the traveller to a place, where the revivification takes place, by means of a forced current of air. This arrangement reduces the purifying labour to a minimum. The purifying material formerly used was a mixture of lime and oxide of iron, lime alone being used in the last battery of the series of purifiers. During last winter experiments were made, with most satisfactory results, on the value of the residue from the roasted pyrites from chemical works. These may be obtained at very low prices, and are superior in purifying power to the above mixture, and also to that of MM. Mallet and Laming, which is composed of sulphate of lime and a metallic oxide, in the form of a hydrate, as of iron, manganese, and zinc. Each purifier and each battery of three purifiers may be isolated from the others. The crane in this department is worked by a Brotherhood three-cylinder engine; the motive power for the purifier, air currents, and the exhausters being supplied by three Galloway boilers of 20 HP.

On its way to the gasholder the gas passes through three counters, or meters, of a measuring capacity of 1,765,000 cubic feet each, placed in a building just outside the purifying house; each counter being 16·4 feet in diameter, and the same in length.

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The gasholders are four in number, three of a capacity of 390,000 cubic feet each, and one of 780,000 cubic feet. The tanks are entirely above ground; the three smaller are of sheet iron, riveted together with tee-iron hoops throughout their whole height; while the larger, 33·45 feet high and 164 feet in diameter, is for the lower 17 feet composed of a series of superposed channel irons riveted together with the flanges outwards, every alternate ring of the lowest six rings being strengthened by tee-iron hoops. The upper part is of sheet iron. The gasholders are single lift, and are without any trussing for the roof, which, when the gasholder is landed, is supported in wooden framework. The gasholders are externally stayed with vertical channel irons and internally have angle iron gusset stays at the top. At the top and at the bottom there are box girders which serve the purpose of stiffeners, and also by being charged more or less with water are employed to adjust the pressure. Gas thermo-siphons are employed to maintain a suitable water temperature during winter. The peculiar feature of these gasholders is, that the gas enters and leaves at the top, instead of, as is usual, at the bottom of the tank by underground pipes. At the two opposite ends of a diameter, are fixed two double tubes, one tube inside another, the space between them being filled with water, to make a hydraulic joint for a pipe which slides therein, and which being fixed to the top of the gasholder rises and falls with it. The gas enters the bottom of the internal tube, after passing through a stop-valve, rises therein and passes into the gasholder through an elbow fixed and strongly stayed thereto. At the top of the moving pipe is a disc valve, so that by this and the valve previously mentioned the gas may be wholly shut off from this telescopic arrangement, either at the exit or entrance side, both being alike. Many advantages are claimed for this system, more particularly with reference to facility for repairs and cleaning, and non-liability of the supply pipes to being broken by contraction or settling of the tank foundations. The arrangement has also the advantage of placing all the pipe connections for entrance and exit of the gas within view.

The gas passes to the town by two mains, one 23·6 inches in diameter, and the other 33·5 inches; the joints being of the conical form, made tight by a ring of india-rubber placed in a groove in the internal or socket part of the joint. Previous to entering these mains the gas passes through a regulator on Girond's system.

W. W. B.

Gasholder of the Berlin Gas Works. By W. SCHWEDLER.

(Zeitschrift für Bauwesen, vol. xxvi., p. 179.)

The diameter of the basin of this gasholder is 179 feet, and the depth of water 25 feet. The foundation level was fixed at

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4·6 feet, and that of the mains at 7·8 feet below the existing ground surface. By far the greater portion of the wall is therefore above the ground, and the pressure of the water against it has to be counteracted by artificial means. This is done, first, by inclining the foundation of the wall outwardly, so that the counter-pressure as well as the distribution of load throughout the building tend to produce radial pressure towards the centre and help to strengthen the wall. It is supported all round at one-third of its height by arched buttresses 3·2 feet in width, which exert inward pressure, and, finally, it is surrounded by earth inclosed by a second wall, which by its weight tends to do the same.

The forces acting radially towards the centre are reduced to figures per lineal yard of wall, as follows:—

	Tons.
Resultant of weight of building and roof, and counter-pressure of foundation	11·42
Pressure exerted by buttresses	22·86
Ditto „ earth	4·57
Total of forces acting inwards	38·85
Pressure of water acting outwards	25·60
	13·25

which makes the actual pressure acting inwards when the basin is full 6·16 lbs. per square inch, and about three times that amount when empty. The superstructure is 184 feet in external diameter, and has sixteen pillars on the inside, with rails attached for guiding the gasholder.

The wrought-iron roof is the segment of a sphere 180 feet in diameter and 40 feet high in the crown. The principle of construction is the same as that introduced by the English Berlin Gas Company, with very slight modifications. It consists of thirty-two radial girders united by seven concentric polygonal rings and diagonal bracings, with a louvre over the centre ring. It is simple, light, and easily erected. The weight of the whole ironwork in the roof is 66·64 tons, and it covers an area of 25,576 square feet.

The gasholder is capable of containing 1,059,500 cubic feet of gas. It is telescopic, and has a diameter of 166 feet in its upper and 169·2 feet in its lower part. Each of these has a height of 24·7 feet. The roof has a radius of 270 feet and a height at the centre of 12·8 feet. The gasholder rests on forty-eight granite stones, which project nearly 6 inches above the basin floor. It is intended to weigh

	Tons.
For the upper part	221·7
„ lower „	61·4
	283·1

Should this not be fully attained, weights are placed on the lower flange of the upper portion.

The pressure the gasholder will exert when the upper part is

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fully lifted equals 4 inches of water, and when the lower part is fully lifted also 5·3 inches of water, the specific gravity of the gas being taken at 0·45.

The cost given is

	£.
Basin and retaining walls	16,785
Building	10,255
Gasholder	7,640
	34,680

The design is by Herr J. W. Schwedler, and the erection was superintended by Herr Reissner.

E. E. S.

Lighting of Trains by Gas in the Mont Cenis Tunnel.

(Bulletin de la Société d'Encouragement, 3rd series, vol. iv., p. 83.)

The system of M. Cambrelin for lighting trains by gas, which has been for some years in use on the Belgian railways, has been recently applied for lighting the trains which run between Turin and Modane, in traversing the frequently occurring tunnels on the line between Bussoleno and Modane—notably the Mont Cenis tunnel. The gas is manufactured from Boghead coal, at the Turin station, and is charged, at a pressure of 7 atmospheres, into suitable reservoirs in the leading break-van, whence it is distributed through pipes to the roof-lamps of the train, where it is burnt at a pressure of $1\frac{1}{4}$ inch (32 millimètres) of water.

The gas is generated in the usual manner, in two cast-iron retorts 4 feet 3 inches long, $8\frac{5}{8}$ inches wide, and $8\frac{5}{8}$ inches high, inside. It is conducted to the purifier, where it traverses eight beds of quicklime, $\frac{5}{8}$ inch in thickness, and passes into the gasholder. From the gasholder, the gas is conducted to a double-acting compressing pump, on Colladon's system, in which the cylinder is cooled by a cold-water jacket, and the piston-rod, which is hollow, is cooled by a current which circulates throughout the whole length of the rod.[1] The pump is by this means maintained at a moderate temperature, and it works well. The compressed gas is discharged into a trap cistern, where tar and other liquids formed by the compressive action are deposited, from which it passes into a vertical cylindrical vessel, where it makes an additional deposit of liquid matters. From this vessel the compressed gas at 7 atmospheres is delivered into two cylindrical reservoirs placed in the break-van, which is brought up to the gas-house to be charged. The reservoirs in the van are constructed of $\frac{1}{4}$-inch sheet iron, double-riveted; they are 2 feet $5\frac{5}{8}$ inches in diameter, and 7 feet $2\frac{5}{8}$ inches long, with a capacity of 30 cubic feet each. The pressure

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlii., p. 239.

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is reduced to that required to be supplied to the burners, by means of a regulator, which consists of a loaded diaphragm of india-rubber open to the atmosphere at the upper side, and exposed on the lower side to the pressure of the gas on its way to the lamps. As the pressure falls the diaphragm sinks, and, by means of a connecting rod, gradually increases the opening of a valve through which the supply passes off to the train. The gas is conducted through an india-rubber tube lined with a brass-wire helix, from which a connection is made with each lamp. The train consists of eight or nine carriages, each having three lamps. Each burner consumes from $1\frac{1}{3}$ to $1\frac{1}{2}$ cubic foot of gas per hour, with an illuminating power of twelve candles. The flame is short, about $1\frac{1}{2}$ inch high. The gas is lowered in daylight, and is turned up on entering a tunnel.

The total cost of the two reservoirs with their mounting complete, for the van, is about £27, of which the reservoirs cost £16. For one carriage, the cost of fittings is about £7; the cost of lighting, calculated for a period of one month, with a consumption of 12,820 cubic feet of gas, is—

	Per 1,000 cubic feet. £.	s.	d.
For the manufacture of gas	1	6	4
For the compression of the gas	0	14	7
For the distribution of the gas, consisting almost entirely of the wages of three men .	0	19	9
Total cost	3	0	8

Say £3 per 1,000 cubic feet, which is sufficient for the supply of twenty eight burners for a period of twenty-five days.

D. K. C.

On the Influence of Pressure on Flames.

By Professor Dr. V. Wartha.

(Journal für Gasbeleuchtung, vol. xix., p. 761.)

Messrs. Frankland and Tyndall[1] found the weights of stearine candle consumed at the levels of Chamounix and Mont Blanc, from an average of five experiments, to be:—

Chamounix: temperature 21°·5 cent. Barometer 26·4.	Mont Blanc: temperature 0°·5 cent.
Quantity per hour . . 9·4 grammes.	9·2 grammes.

In 1841 the French engineer Triger remarked that candles burnt away more quickly under a pressure of 3 atmospheres than at ordinary atmospheric pressure.

The Author found from the average of six experiments, that

[1] *Vide* Phil. Trans. 1861, vol. cli., p. 629.

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candles burning in free air, at a temperature of 18° centigrade, and in a caisson under a pressure of 1·95 atmosphere, consumed—

	Length of Flame.	Quantity per Hour.
In a caisson	3·80 inches.	8·61 grammes.
In free air	2·08 „	9·91 „

The Author mentions various results arrived at by Davy, Le Conte, and others, and then describes his own apparatus and experiments as follows:—

An ordinary air pump and receiver, as improved by E. S. Ritchie, was the only one found to answer. The receiver was provided with a small pipe regulated by a tap, and terminated by a funnel containing cotton wool, through which air could enter. The exhaust opening was provided with a vertical tube extending about two-thirds of the height of the receiver, and through this the gases produced by combustion were withdrawn. A stearine candle was fixed on a cork, and placed on the plate of the air pump under the receiver. A wire stood vertically near the candle, and was provided with a horizontal platinum arm for measurement of the flame. This arm was set at the height the flame reached when burning in the rarest atmosphere.

When the pump is set in motion the light given off by the flame diminishes. The flame swells out like a blue ball, separates entirely from the wick, and takes the shape of a cap. When the pressure is reduced to 90 millimètres (3½ inches) the light from the flame disappears, the flame becomes treble its original size, and appears to be composed of three parts—the bluish-green inner ball appears to be encircled by a violet casing, and this appears again bounded by a scarcely visible light violet cap. This latter is only visible if a lithium or natrium bead is attached to the platinum wire.

From time to time a fine spray of sparks bursts out from the interior of the flame. These sparks recur most often when the atmosphere is at its least density or 3½ inches pressure.

The reason of the phenomenon described is simple. As the quantity of air is diminished the temperature of the point at which decomposition takes place is raised—or, in other words, the less the pressure under which the flame burns the less soot is formed.

In conclusion, the Author mentions that Triger's first experiments allow the supposition that the tallow candles he used were simply melted by the high temperature of the apparatus, whilst Cailletet's and the Author's experiments show the deposition of great quantities of soot.

The supposition of Le Conte that the process of combustion is retarded by less dense and quickened by denser air is not true. On the other hand, Frankland's results are confirmed, which show that within certain limits combustion is more complete as the air becomes less dense.

J. J. T.

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Mechanical Separation of Matters in Suspension in Gas or Vapours. By F. Le Blanc.

(Bulletin de la Société d'Encouragement, 3rd series, vol. iii., p. 465, 1 pl.)

The construction of the apparatus at present usually employed for the separation of matters held in suspension in coal gas, is founded upon the principle of condensation, by reduction of temperature, of those matters, and of the gas supporting them, by contact with large surfaces cooled by water, or by contact with the water itself. Condensation by compression has received but little attention. MM. Pelouze and Audouin, having noticed how tenaciously liquids in the globular or vesicular state are retained by gas, even during transport, have sought to arrest these vesicles by causing them to strike against solid surfaces, after passing under a pressure of about 2·2 inches of water through a finely perforated metallic plate. The liquid globules held in suspension by the gas, being arrested by their passage through the small holes, break against the surface of the second plate, dissolve, and, acquiring sufficient weight to cease to remain in suspension, trickle down the surface of the plate into a suitable reservoir. It has been found by experience that gas on its way from ordinary scrubbers, &c., to the purifiers, quickly blackens pieces of white paper held over an escaping jet, but that when the same gas has previously passed through the condenser constructed on this system no such blackening takes place, the tar, &c., being completely removed, so that the work to be done by the purifiers is greatly lessened. The quantity of purifying material required is much reduced, and labour is saved by the less frequent necessity for removal and renewal. The condenser, which is fully illustrated, consists mainly of an outer casing with a gas inlet at the lower part, and an outlet at the upper. Suspended within the casing is an annular water tank, in which is balanced a miniature gas-holder, or bell formed with four circumference plates, two of which are perforated, in rows, with small holes, and two with large holes; the latter being opposite the blank spaces between the rows of the former. The gas from the inlet, passes through the central space within the annular tank, and through the four perforated plates of the bell; the tar, &c., which condenses on the non-perforated portions of the surfaces trickles down the plates into the water tank. The bell, being balanced in the water to suit a normal pressure of gas, rises and falls with an increase or decrease of pressure, so that a larger or smaller number of perforations is open to the passage of gas. The condenser thus acts also as a regulator. It has been found that if the perforated bell has a capacity of 35·317 cubic feet, it will suffice for works producing 3,531,700 cubic feet per twenty-four hours, or in the proportion of 1 to 100,000.

At the gasworks in Paris, producing the above quantity of gas,

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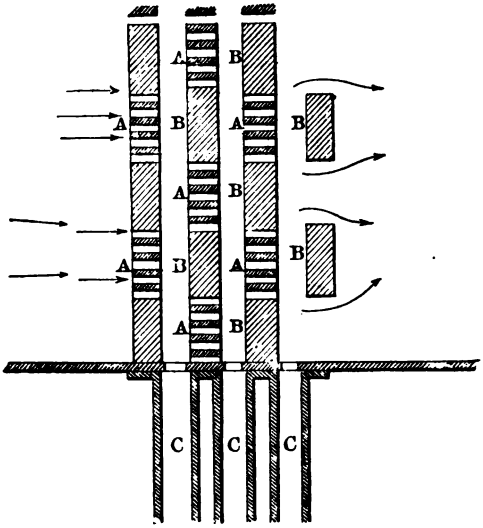
the condenser retained 19·6 lbs. of tar and about 1·9 pint of rich ammoniacal liquor per 35,300 cubic feet of gas. At a small works, with the condenser passing the same quantity of gas, 158 lbs. of tar and 28 pints of liquor containing 693 grains of ammonia per pint were obtained.



The diagram here appended indicates the principle of action of the condenser. The moving gas meets the first plate, and passes through its perforations, A, from whence it is directed against the plain parts, B, of the second plate, and passing on thence through its perforations, A, it meets the plain parts, B, of the third plate, through which it afterwards passes to the main; each impingement against the plain parts being attended by the retention, on these parts, of the liquefiable matters in the gas, which afterwards trickle down the plates into the outlets, C C.

W. W. B.

Application of the Mechanical Theory of Heat to the Study of Volatile Liquids, Simple Relations between the Latent Heat, Atomic Weight and Tension of Vapours. By R. PICTET.

(Annales de Chimie et de Physique, vol. ix., p. 180.)

If a pound of any liquid at the temperature $t°$ be assumed to pass from the liquid to the gaseous state at this temperature, and at constant pressure P, it absorbs a quantity of heat represented by λ, the latent heat of evaporation, and the volume v of the liquid

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becomes the volume V of the vapour. Now, as λ, V, and P differ with every liquid, the question for consideration is whether they are independent variables, to be determined empirically for each liquid, or whether they are connected. M. Regnault's immense series of experiments afford the means of proving any theory on the subject.

Suppose a refrigerator, A, contains a volatile liquid of the specific heat c, and of which the latent heat is λ at $t°$, and that a pump, B, draws the vapour (of the density δ as compared with air) formed in A, at constant pressure P and temperature $t°$, performing the work T, and forces it into a condenser, C, at constant pressure P′ and temperature $t'°$, and that the cycle is completed by means of a tube, D, which allows the vapour from A, condensed as liquid in C, to return to A: also suppose $t' > t$, and $P' > P$. From Regnault's data can be calculated, first, the heat drawn from A by evaporation of the liquid, less the heat given up by the return of the liquid from the temperature t' to t; secondly, the work expended by the working of the pump B to compress the vapour from P to P′. These equations are quite independent, and give, the one a quantity of heat, the other a quantity of work.

The laws of Mariotte and Gay Lussac are supposed exact, which is not rigorously the case. The co-efficient of expansion of gases is $\frac{1}{461}$ per degree Fahrenheit ($\frac{1}{274}$ per degree centigrade), ·080728 lb. the weight of a cubic foot of air (1·293 kilogramme for a cubic mètre), and 2,116·3 lbs. the atmospheric pressure per square foot (10,333 kilogrammes per square mètre). The calculations are made for a pound (kilogramme) of liquid. First, with regard to the work T, produced by the compression of the vapours at $t°$ whilst passing from pressure P to P′, the calculation gives

$$T = \frac{2{,}116{\cdot}3\ (461 + t)\ \text{Nap log}\left(\frac{P'}{P}\right)}{{\cdot}080728\ \delta \times 461}\ \text{foot-lbs.};$$

$$T = \frac{10{,}333\ (274 + t)\ \text{Nap log}\left(\frac{P'}{P}\right)}{1{\cdot}293\ \delta \times 274}\ \text{kilogrammètres} \quad (1)$$

The Napierian logarithm of $\frac{P}{P'}$ is introduced by integrating the work between these limits of pressure.

Secondly, with regard to the heat absorbed in the refrigerator A. For a pound (kilogramme) of liquid this is

$$\text{Heat absorbed in heat units} = \lambda - c\ (t' - t) \quad . \quad . \quad . \quad . \quad (2)^1$$

These equations are absolutely dissimilar. Suppose there were two liquids of the same density, tension, and specific heat, but that

[1] For t in Fahrenheit degrees substitute 461 for 274.

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the cohesion of the first were double that of the second, so would be its latent heat, since this is the quantity of heat absorbed in overcoming molecular cohesion, whilst T would be the same in both liquids.

Or, again, if the specific and latent heats and tensions are supposed the same in both, but the vapour density of the one double that of the other, the work would be double in one case what it was in the other, whilst the heat absorbed would be the same in both cases.

Thus, without any hypothesis on the constitution of liquids and gases, the two equations remain essentially independent. There are two suppositions made. The first is that the cohesion of liquids is constant for all; this furnishes a relation between equations (1) and (2). The second hypothesis is that Carnot's cycle is applicable to volatile liquids, and to their changes of volume when they volatilise, and that it establishes the relation between the work expended and heat absorbed. If this second hypothesis does not hold, a Carnot and volatile liquid cycle might be connected, whose difference would be represented by the transformation of a certain amount of atmospheric heat into mechanical work.

If these hypotheses are introduced into equations (1) and (2), there is obtained, for English and metric measurements respectively,

$$\frac{2{,}116{\cdot}3\,(461+t)\,\text{Nap log}\left(\frac{P'}{P}\right)}{{\cdot}080728\,\delta\times 461}=\frac{[\lambda-c\,(t'-t)]\,J\,(t'-t)}{461+t}$$

$$\frac{10{,}333\,(274+t)\,\text{Nap log}\left(\frac{P'}{P}\right)}{1{\cdot}293\,\delta\times 274}=\frac{[\lambda-c\,(t'-t)]\,E\,(t'-t)}{274+t}\qquad(3)$$

wherein J (E) is the mechanical equivalent of heat; and from this

$$\lambda-c\,(t'-t)=\frac{2{,}116{\cdot}3\,(461+t)^2\,\text{Nap log}\left(\frac{P'}{P}\right)}{{\cdot}080728\,\delta\,J\times 461\,(t'-t)}$$

$$\lambda-\quad(t'-t)=\frac{10{,}333\,(274+t)^2\,\text{Nap log}\left(\frac{P'}{P}\right)}{1{\cdot}293\,\delta\,E\times 274\,(t'-t)}\quad.\quad.\quad.\qquad(4)$$

The Author next compares this last equation with the results of Regnault's tables. Water is taken, and the results compared at $t = 100$ and $t' = 110$; the constants are $P = 760$, $P' = 1075{\cdot}37$, $\delta = 0{\cdot}625$, $c = 1$, $E = 433{\cdot}5$, $\frac{P'}{P} = 1{\cdot}41496$. The calculation is given in full in the Paper, and $\lambda = 532{\cdot}63$. In Regnault's tables this quantity for $100 = 536$; the difference is about $\frac{1}{700}$ of the experimental value.

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Equation (4) differs essentially from those of Clapeyron, Clausius, Zeuner, &c., as they entirely neglect the term $c\,(t' - t)$.

By considering the latent heat at the point of ebullition or atmospheric pressure, the last equation can be simplified: for P converging towards P', the difference $t' - t$ converges to zero, and the fraction

$$\frac{\text{Nap log}\left(\frac{P'}{P}\right)}{t' - t}$$

becomes the derivative of the logarithm of the pressure with respect to the temperature, which is shown farther on to have the value

$$D\,\frac{\text{Nap log}\left(\frac{P'}{P}\right)}{t' - t} = K\,\frac{274}{274 + t} \quad . \quad . \quad . \quad . \quad (5)^1$$

A table is given showing the value of the latent heat as calculated and as found experimentally by Regnault for many liquids—water, alcohol, mercury, &c.; and the differences are easily explained by the variations in the law of Mariotte, and by errors of observation. Another table shows that K, as calculated from the above equation (5), is a constant nearly equal to 0·041; for instance, in liquids so different as mercury and sulphuric acid there is only a difference of $\frac{1}{15}$.

Next, let a be the weight of a liquid atom, and F the cohesion which binds the atom to those surrounding it. The effort of heat, and of its work of disaggregation, are exactly represented by the latent heat at the temperature.

The number of atoms contained in a unit of weight is $\frac{1}{a}$; but a must be taken at the temperature t; that is, the density of the atom, variable with the boiling temperature. Integrating the elementary work for a unit weight, the sum represents the internal latent heat at the temperature, or

$$\lambda = \frac{K\,(274 + t)}{a \times 274} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)^1$$

whence

$$K = \frac{274\,a\,\lambda}{274 + t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)^1$$

and dividing by the factor 274, constant for all liquids,

$$K = \frac{a\,\lambda}{274 + t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)^1$$

A further table, in which the latent heat is multiplied by the atomic weight of some of the different liquids experimented on, gives

[1] For t in Fahrenheit degrees substitute 461 for 274.

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a nearly constant number; showing that the cohesion is the same in them all, and that therefore the hypothesis is correct.

It is also shown theoretically, and proved by reference to experiment, that for any two temperatures the difference of the internal latent heat multiplied by the atomic weight is a constant for all liquids. This agreement is shown in three different tables of very varying temperatures, and must be considered very close when the difficulty of observing the latent heat is considered.

From what precedes the following conclusions are drawn:—

1. Cohesion is constant for all liquids.

2. The derivative of the Napierian logarithm of the quotient of the tensions with respect to the temperatures is constant for all liquids when brought to the same pressure and temperature.

3. The latent heat of all liquids brought to the same pressure, multiplied by the atomic weight brought to the same temperature, gives a constant product.

4. For all liquids, the difference of the internal latent heat at any two temperatures, multiplied by the atomic weight, is a constant quantity.

Hence quantities formerly considered independent are connected by very simple relations.

With respect to the law of Dulong and Petit on specific heat, it may be combined with the laws of latent heat just traced, in the statement that the latent heat of each liquid is a multiplier of the specific heat.

E. B.

Hypothesis on the Condensation and Re-evaporation of Steam in the Cylinders of Steam Engines. By J. ILLECK.

(Civilingenieur, vol. xxii., p. 371.)

The theory of the steam engine, established by Clausius, and developed by Zeuner, stood until lately unopposed, and it appeared that a solution of this difficult problem had been found. The indefatigable labours of Hallauer, Leloutre, and Hirn,[1] however, have within the last few months succeeded in effectively attacking this theory, and in throwing the investigations back to a condition resembling chaos.

In comparing the effective weight of steam at the end of the period of admission, or at any point of the period of expansion, with the feed water required per stroke, a difference will be found to exist, which may amount to from 20 to 70 per cent. According to the older views, this difference is ascribed to condensation of steam in the steam passages (by experiment proved to be very slight in clothed pipes); to leakage of the piston; or to priming water carried over from the boiler; while but little importance has been hitherto attached to condensation of steam in the cylinder

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlvii., p. 376.

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itself. Hallauer and Leloutre, however, assume that the boiler steam contains generally not more than 5 per cent. of water in the form of spray; that but little weight need be attached to priming water carried over from the boiler in a coarser condition; and that the steam increases its water content, at its entrance into the cylinder, by condensation against the cylinder walls.

The amount of condensation depends on the ratio of expansion, and on the presence or absence of a steam jacket. Without a jacket it may be 60 per cent. or more; with a jacket it is reduced to about 40 per cent. According to Zeuner, the expansion is adiabatic, and an equivalent decrease of the heat in the steam corresponds to the external work done. For this the mere fall of temperature of the steam only partially accounts, and the remainder is due to condensation. At the end of the expansion, therefore, the amount of steam is diminished, and the water-contents of the cylinder increased. According to Hallauer and Leloutre, the steam, during expansion, takes heat from the cylinder walls; there is re-evaporation, and diminution of the water contained in the cylinder, and part of the heat, given to the cylinder walls during admission, is supposed to be given back to the steam during expansion, when the temperature of the latter has fallen below that of the cylinder walls. In this way they estimate an increase of 40 to 60 per cent. when there is no jacket, and of 55 to 85 per cent. when there is; while the leakage of the piston is neglected.

The greatest difference of opinion, however, exists in the consideration of the period of condensation. According to Zeuner, the steam, with the water contained in the steam, is at the end of the expansion simply driven into the condenser. According to Hallauer and Leloutre, that water is chiefly re-evaporated at the expense of the heat in the cylinder walls. If there is no jacket, the re-evaporation during expansion is not so great as during release, but with a jacket it is greater. To these later views, able though they be, and plausibly though they explain the excess of the feed water over the theoretical quantity of steam required, the Author raises the following objections:—

1. It is inconceivable that in the short time required for admission so important a quantity of heat as corresponds to the condensation of 55 per cent. of the steam can be imparted to the cylinder walls.

2. It can be shown that the mean temperature of the cylinder walls without a jacket must approximate to the temperature of the steam at the end of the expansion. Under these circumstances it is difficult to see that heat can be given to the steam during expansion.

3. If such a rapid exchange is assumed as possible, it follows that when a jacket is used the cylinder walls must be constantly, throughout their entire extent and thickness, of the temperature of the boiler steam, to secure which the heat supply must be enormous.

Between the return stroke of an engine with a jacket and the

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admission period of an engine without a jacket there is an analogy, as for both the temperature difference of the walls and steam is constant, and under similar circumstances approximately the same. Between the heat passing from the cylinder to the steam in one case, and from the steam to the cylinder in the other, there must exist a ratio, depending on the mean surface of metal exposed and upon the time. If this be calculated, it will be found that the heat given to the cylinder walls during admission must be very small, or the heat abstracted from a jacketed cylinder during the return stroke would be preposterously large.

4. It appears incomprehensible, why with a jacket the condensation during admission does not nearly vanish. In fact, however, the condensation is about 40 per cent., or only 15 per cent. less than when there is no jacket. This is not attributable to the cooling surface of the piston.

5. That the heat exchange between the walls and jacket cannot be very great is shown by the small condensation in the jacket.

6. If the condensation during admission were merely due to the cold cylinder walls, superheated steam ought to give very advantageous results.

The Author then gives his own hypothetical views on the phenomena which occur in the cylinder. He assumes:—

1. The water contained in the steam coming from the boiler is of two kinds: (*a*) Water distributed as fine spray throughout the whole mass of the steam. This from Hirn's researches should not exceed 10 per cent. of the weight of the steam. (*b*) Priming water thrown up by violent ebullition and carried over to the cylinder. This water may be small in quantity, or may reach 60 per cent. of the weight of the steam.

2. The condensation during admission may be partially due to the coldness of the cylinder walls, but a far greater part of the condensation is due to a very different cause. Consider the piston at the end of the stroke and the connection with the condenser established. The steam will pass off into the condenser with the smaller part of the water it contains, which is distributed through it in the form of spray. The greater part of the water in the cylinder remains adhering as a deposit of dew on the cylinder walls. Assume, as a limiting case, that the motion of the piston is very slow. Then, at the beginning of the return stroke, this deposit of dew will have taken the temperature of the condenser, generally in consequence of re-evaporation at the expense of the heat it contains. During the return stroke, this water is driven into the clearance space, a great part of it still covering the surface of the piston and cylinder cover. During admission this must, for the most part, be raised again to the boiler temperature, by condensation of part of the incoming steam. The fine dew covering the surfaces of the cylinder probably takes the boiler temperature instantly, while the remainder of the water which lies in a mass is gradually raised in temperature during the admission, without quite reaching the boiler temperature. The amount of

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water on the surfaces is not trivial. If it amounted to three times the feed water per stroke, and were uniformly distributed on the surfaces, it would yet form a layer of less than 0·08 inch thickness. Thus the presence of water affords an explanation of the condensation during admission. This water will in future be called the vacuum water (*Leerwasser*) of the engine.

3. The most striking confirmation of the existence of vacuum water is found in the phenomena of expansion. Proceeding still with a hypothetical case, let it be assumed that the boiler steam and vacuum water form a mixture of uniform temperature at the beginning of the expansion, and that this mixture expands adiabatically. The expansion of such a mixture when steam preponderates is accompanied by partial condensation, but if the water preponderates, by partial re-evaporation. Now the vacuum water, as has been seen, is greater than the feed water per stroke. Hence, during expansion, there is partial re-evaporation, and this is so considerable that there might be evaporation even when the steam parted with some heat.

4. If the piston moves very slowly, the vacuum water will alternately cool to the condenser temperature, and be heated to the boiler temperature, and the assumption of adiabatic expansion will not be strictly admissible. If the piston moves very fast, the expansion would be adiabatic, but for the circumstance that the vacuum water does not reach the boiler temperature during admission, and the mixture in the cylinder is not of uniform temperature. These considerations make it possible to explain the difference in the action of engines with and without jackets.

In an engine with a jacket there is less vacuum water, and that water more easily adapts itself to the changes of temperature. It is more heated during admission, and more cooled during exhaust; nevertheless the condensation during admission is smaller, because it is determined by the quantity of the vacuum water. The comparison of the two cases during expansion is more complicated. The smaller quantity of vacuum water in the former case (with a jacket) would involve a less re-evaporation, but its higher temperature would lead to a greater evaporation. Probably with a jacket the evaporation during expansion is earlier and more energetic, and, on the whole, greater.

5. The vacuum water is reduced in quantity, but never vanishes. This explains why, notwithstanding the jacket, there is condensation during admission.

6. For moderately superheated steam the vacuum water should be diminished, yet it remains sufficient to reduce the steam to saturation, and to condense part of it. Hence it may happen that moderate superheating leads to no striking advantage. Highly superheated steam ought to do great service, if it prevents the formation of vacuum water.

The Author then discusses the action of priming water, and gives a mathematical theory based on his hypothesis.

W. C. U.

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Manometer for High Pressures. By L. Cailletet.

(Comptes rendus de l'Académie des Sciences, vol. lxxxiii., p. 1211.)

In a former article[1] the Author has made known the results of his experiments on the resistance of glass tubes to rupture, viz.: (1) that the quantity by which a cylindrical glass reservoir varies in volume, when compressed externally, is proportional to the pressure exercised, and that within very extensive limits; (2) that the glass is not subject to permanent deformation. Based upon these properties, the Author has constructed a simple manometer, which indicates high pressures with accuracy, and the sensibility of which may be made as great as required.

The apparatus consists of a glass thermometer, the cylindrical reservoir of which, being terminated by a spherical chamber, is filled with mercury. The capillary tube, accurately graduated, is fastened to the reservoir, which has a swelling intended to be fixed, by means of gutta-percha, in a copper cock which accurately closes the orifice of a stout steel reservoir. When water is compressed in this metallic reservoir, pressure is exerted on the sides of the glass cylinder; the mercury displaced by the diminution of the volume of its chamber rises in the capillary tube to heights corresponding to pressures previously determined for each manometer. To obtain exact indications it is necessary to maintain, by means of ice or water, a constant temperature in the apparatus. The sensibility of manometers constructed on this principle may be made as great as desired by modifying the relation of the diameter of the reservoir to that of the capillary tube.

The Author has employed this manometer to measure pressures at great depths in the sea, an index being attached.

P. H.

Efficiency of Steam Vacuum Pumps. By J. Foster Flagg.

(Transactions of the American Society of Civil Engineers, vol. v., p. 381.)

A simple method is described for ascertaining the efficiency of the class of steam pumps, on Savary's old system, known as steam vacuum pumps, pulsometers, or aquameters. Experiments were made on such a pump at the Cincinnati Exhibition of 1875. The supply of steam was drawn from two pairs of boilers, connected by a 4-inch pipe covered with asbestos cement. The water was drawn directly from a canal, through a 3-inch pipe, 155 feet long, with a lift of 10·83 feet. The Author has arranged some simple formulæ, based on the latent heat of steam, and the elevation of temperature of the water in the pump by the condensed steam; by means of which the consumption of steam and the efficiency of the pump were deduced. A preliminary test was applied, for the purpose of

[1] Comptes rendus de l'Académie des Sciences, vol. lxxxiii., p. 411.

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measuring the quantity of water in mixture with the steam supplied to the pump. The water was found to amount to 25 per cent. of the steam consumed, and due allowance was made for it. The head of pressure was regulated by a cock applied to the discharge pipe; and the pressure gauge was applied immediately above the pump. The leading average results of two experiments made by Mr. Flagg are:—

		1st Trial.	2nd Trial.
Effective pressure in the boilers	lbs. per square inch	71·85 lbs.	56·71 lbs.
Temperature of water in canal	Fahr.	60°	61·5°
„ effluent water	„	86·93°	73·07°
Pressure of water at the gauge	lbs. per square inch	35·29 lbs.	16·29 lbs.
„ „	feet of head	81·81 ft.	37 68 ft.
Steam consumed per HP. per hour	lbs.	477·5 lbs.	390·7 lbs.
Coal „ „ allowing 9 lbs. of steam per lb. of water	lbs.	53·06 lbs.	43·41 lbs.
Duty per 100 lbs. of coal	foot-lbs.	3,732,260	4,561,200

The Author communicates the results of a trial of a pump of this class employed for supplying water tanks on the Atlantic and Great Western railroad: the suction pipe was 24 feet long; and the lift, including friction, was 7·97 feet. The delivery pipe was 211 feet long, and rose to the top of the tank, giving a constant head. The steam pipe from the boiler was 1 inch in diameter.

	1st Trial.	2nd Trial.	3rd Trial.
Total lift from well to tank, including friction	44·58 ft.	40·28 ft.	44·16 ft.
„ pump to „ „	36·61 ft.	32·83 ft.	36·18 ft.
Temperature of water in well . . Fahr.	40°·60	47°·50	47°·43
„ „ above pump . „	50°·93	56°·14	57°·23
Effective pressure in boiler	60 lbs.	20·8 lbs.	38·6 lbs.
Number of single strokes per minute	51·8	33·4	50·14
Quality of steam (proportion of steam in the mixture of steam and water supplied to the pump)	Per cent. 68	Per cent. 81	Per cent. 88
Coal per HP. per hour	40·2 lbs.	39·78 lbs.	41·83 lbs.

The Author considers that a higher suction and a lower lift would have given somewhat better results.

D. K. C.

On an Underground Pumping Engine at Fohnsdorf.

By B. Hess.

(Berg- und hüttenmännisches Jahrbuch (Leoben), vol. xxiv., p. 311.)

The tertiary coal-field of Fohnsdorf, near Judenburg and Zeltweg, in the valley of the Mur, belongs to the Styrian Iron Company, who have sunk three shafts, about 500 yards apart, from which levels are driven at vertical intervals of about 57 yards to intersect the coal seam.[1] At present the coal is in process of removal at the first and second levels, and two of the shafts have been sunk to a

[1] This according to another authority is from 9 to 15 feet thick.—H. B.

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third level, 180 yards below the surface, in preparation for deeper working.

In the first stage of the workings a 30-HP. pumping engine in each shaft, working two lifts of 9½-inch pumps, the rods being moved by spur gearing and bell cranks, proved sufficient to keep the mines dry, but with increased depth the volume of water encountered became very much larger, so that further pumping power became necessary. This has been supplied by sinking a rectangular shaft of small size (5 feet in the side and 27 square feet available area) near the centre of the field worked, at a point 72 feet south, or on the dip side, of the deepest drawing shaft, to a depth of 600 feet. The sump of this shaft, being connected by levels with the lower workings of the different mines, receives the whole of their drainage water, which is lifted to the surface by a pair of direct-acting pumping engines placed near the bottom of the shaft. The chamber containing the engine, which is 52·9 feet long and 20·7 feet broad, is cut out of the rock, and was at first only partially secured by walling on the sides and roof, the ground, consisting of strong shales and hard coal, being sufficiently firm; but, when nearly completed, a fault in the strata was cut through, which disturbed the ground to such an extent that the floor began to thrust upward, so that it became necessary to line the entire excavation with masonry. The form of the work as finished is similar to that of a railway tunnel. The sections of the roof, side walls, and floor are semicircular, the respective radii being 10·3 feet, 20·7 feet, and 17·2 feet. The walling, which is 25·6 inches thick, except where the fault is crossed, where it is increased to 32·3 inches, is carried out in common brickwork set in cement, except the key-stones of the roof and the floor arch, which are in specially moulded large fire-bricks. The engine bed is also in brickwork and cement, squared blocks of stone being used to take the pull of the holding-down bolts. Four transverse girders of wrought iron are built into the walls above the engines to facilitate the removal of any parts of the machinery for examination or repair.

The engines, which are designed to lift 695 gallons of water 623 feet high per minute, with a working steam pressure of 4 atmospheres, and 149 feet per minute piston speed, are of a horizontal direct-acting pattern, with variable expansion (Meyer's) gear and condensing. The fly-wheel, to which both engines are coupled, weighs 10¼ tons, is 18·4 feet in diameter, and is placed behind the steam cylinders. The pumps, having each two working barrels, with a plunger common to both, are placed between the steam cylinders and the air pumps, which are also double-acting. The steam cylinders are 33 inches, the pump plungers 10·8 inches, and the air pumps 12·4 inches in diameter, the length of stroke common to all these being 27·3 inches. There are two valve boxes and air vessels to each working barrel of the pumps. The valves consist of metal balls, twenty-one in each box, 2·48 inches in diameter and 0·315 inch lift, giving a clear water-way of

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1·7 inch, so that at every stroke made by the pump forty-two suction, and the same number of pressure valves, are put in action. The valve seats, also of metal, are arranged in a step form, and the boxes are placed to the right and left of the working barrels so as to get the largest amount of clear water-way without making any part of undue size. The valve boxes in each pair are united below by a suction pipe 5·7 inches in diameter, and the four sets of pressure valves in each engine discharge into an overhead main of 8·85 inches, which is connected by a similar one from the other engine, with the common rising pipe of 12·4 inches in the shaft.

The condenser valves, of which there are eight to each engine, are india-rubber discs, 6·63 inches in diameter, and the air pump is so arranged that it may act as a suction lift to the main force pump, the latter being, however, provided with independent suction pipes in order to lift directly from the sump if necessary; the height of the suction lift is about 16·4 feet.

The exhaust steam from the engines is admitted to the condenser by a mouthpiece containing three conical diaphragms, having a clear annular aperture of 7·28 inches, within which the main suction pipe is placed concentrically. The water from the latter causes a rapid flow of steam through the conical tubes; and both currents being brought into intimate contact by the diaphragms, rapid and complete condensation is effected. The condensers are so arranged, however, that the exhaust steam may be diverted and passed out by a waste pipe to the surface when the engines are worked without condensation. The actual height to which the water is lifted is only 570 feet, but as it is intended to establish coal-dressing machines at the surface, which will require the point of discharge to be placed at a higher level in order to obtain the necessary head for the washing water, the engines have been constructed to work under 623 feet head, corresponding to a pressure of 19 atmospheres, under which conditions the total pressure upon each plunger is about 10 tons, and that on the steam pistons, with an absolute steam pressure of 5 atmospheres, about 20 tons. The net power required, apart from all resistances, is about 130 HP. The pump barrels, valve boxes, and air vessels, which are of cast-iron, strengthened with rings and feathers, have been proved to a pressure of 40 atmospheres, and all surfaces of contact are united by turned shoulders fitting into corresponding sockets. The cranks, piston rods, cross heads, and similar moving parts, are of Bessemer steel. The total weight of the engines, exclusive of fly-wheel and connecting pipes, is 55 tons.

The boilers, five in number, are placed above ground, and the steam is conveyed to the engines by a pipe 9·84 inches in diameter, coated with non-conducting material to prevent loss of pressure as much as possible. The loss of pressure between the boilers and the engines, which are 715 feet apart, was 6½ lbs. upon an initial pressure of 60 lbs., or 10·8 per cent., with a naked steam pipe, but

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when a length of 328 feet was covered this was reduced to 5 lbs., or 8·3 per cent.

The rising pipe in the shaft is of cast iron, 12·4 inches inside measure, the thickness being tapered, according to position, in four series, proportionally to the resistances, in the following order:—

19	atmospheres	1·210 inch	(30·8 millimètres)
13½	„	0·990 „	(25·2 „)
9	„	0·798 „	(20·3 „)
4½	„	0·688 „	(17·5 „)

The separate lengths are united by turned flanges with double india-rubber packing rings.

The engines were started at the end of July 1876, and delivered, at the normal working speed, 757 gallons of water per minute, or about 87 per cent. of the theoretical discharge of the pumps. The variations of pressure, as observed by a gauge placed at the bottom of the rising pipe, is between 18 and 19 atmospheres. Experiments have also been made by disconnecting one pump and running the other with both engines. Under the latter conditions, when the number of revolutions did not exceed twelve to thirteen per minute the variation of pressure was very slight, at fourteen revolutions it was included between 19 and 22 atmospheres, and at nineteen or twenty revolutions fluctuated between 8 and 30 atmospheres. The great difference in resistance under the latter condition is to be attributed to the circumstance that when the position of the crank is between 0 and 90° the water in the rising pipe is accelerated, and similarly between 90° and 180°, retarded in its movement. It would therefore be necessary to put on a special counterpoise in order to work the engines effectively under this condition. In spite, however, of the great variations in resistance observed in the latter experiment, the engines worked perfectly smoothly, and the fluctuations of pressure noticed could only be detected by observing the gauge. When working fourteen hours out of the twenty-four, which is sufficient to draw the water for the present extent of workings, the consumption of small slack or dust coal is about 11 tons.

The total cost of the engines and necessary works, together with that of an engine of equal power above ground working pumps in shaft, is given as follows (the florin taken at 2*s.*):—

	£.
1. Sinking engine shaft and connecting level . . .	2,223
2. Cost of engine chamber.	1,413
3. Five boilers, boiler-house, and stack	3,875
4. The pumping machinery, complete	1,798
5. Rising pipe in shaft	722
6. Main steam pipe in shaft	398
7. Exhaust „ „	113
8. Suction pipe to sump	59
9. Freight, cartage, and erection charges	683
	11,284

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The following estimate of cost of engine at the surface is calculated for a 70-inch single-cylinder direct-acting engine with a stroke of 106 inches, placed above the mouth of the shaft, working two plunger lifts of 2·06 feet in diameter at four strokes per minute, the excess weight of the main rod being counterpoised by a balance box:—

	£.
1. Cost of shaft and connecting levels; the former being of 68·9 square feet section	2,500
2. Five boilers, as above	3,875
3. Engine-house, and foundation for the steam cylinder (wrought-iron girders above mouth of shaft)	1,550
4. Wrought-iron main rod and connections for pump lifts (about 70 tons)	1,540
5. Cast-iron rising pipe, 23·6 inches internal diameter, tapered in thickness as before	1,280
6. Steam pipe and connections	30
7. Cost of engine	2,000
8. „ two plunger lifts	1,200
9. „ counterpoise for rods	130
10. Freight, cartage, and erection	1,020
	15,125

The underground engines have therefore been erected at a smaller first cost of about £3,840.

H. B.

On the Theory of the Centrifugal Pump.

By Professor R. Escher, of Zurich.

(Civilingenieur, vol. xxii., p. 634.)

The accurate theory of the centrifugal pump gives for the relation between the velocity w_2 of the circumference of the pump disc, and the relative velocity of discharge c_2 of the water, an equation of the following form:—

$$c_2 = a w_2 + \sqrt{\{w_2^2 [a^2 + (1 - \lambda^2) b] - 2 g h b\}} \quad . \quad . \quad (1)$$

where a and b are constants depending on the construction of the pump, λ is the ratio of the internal and external radii of the disc, and h is the lift.

By plotting values of w_2 as abscissæ and corresponding values of c_2 as ordinates an hyperbola is obtained, the origin being at the centre and the axes inclined to the axes of co-ordinates. The lower branch of the hyperbola has generally no significance, but one point of it corresponds with the condition curve of the pump. That is the intersection of the hyperbola with the axes of x, which has for abscissa

$$w_a = \sqrt{\frac{2 g h}{1 - \lambda^2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

This is the velocity at which the water column is sustained by

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the rotation of the pump without aid from the foot-valve. For a small increase of velocity the full discharge begins, not gradually, but suddenly. It is known that a centrifugal pump will not easily give a small discharge. The latter rises suddenly from zero to a value corresponding to c_a found by substituting w_a from (2) in (1). There is discontinuity, and the condition of equilibrium is unstable. This has sometimes been ascribed, without reason, to the inadequacy of the theory, because at the moment when motion of the water column begins the pressures in the pump alter. If there is really unstable equilibrium, and the pump is allowed to decrease in speed after it has been working, then when $w_2 = w_a$ it will not at once cease to discharge, but will continue pumping as long as the expression under the root in (1) is positive, or till

$$w_2 = \sqrt{\left\{\frac{2ghb}{a^2 + (1-\lambda^2)b}\right\}} = w_m.$$

If w_2 is further diminished, equation (1) gives imaginary values of c_2; at that point, therefore, which still corresponds to a finite discharge, the pump suddenly ceases to lift. There are, thus, two different equilibrium points—one for the condition of rest and one for the condition of motion. Both are, according to the direction, unsteady. It is not absurd, consequently, if calculation gives positive values for the discharge for velocities less than the starting velocity. The Author then mentions an experiment on a pump which started pumping at thirty-six revolutions, but in which the speed could be reduced to thirty-two revolutions before it again stopped pumping.

In Dr. Hartig's experiments,[1] with a lift of 3·92 mètres (12·9 feet), the speed corresponding to equilibrium was found to be 442 revolutions. Taking $\lambda = 0{\cdot}3733$, then $w_a = 9{\cdot}453$ mètres (30·6 feet), which corresponds to a speed of 480 revolutions, instead of 442, as observed. The Author ascribes this discrepancy to the rotation of the water in the case surrounding the pump disc.

The Author then discusses some other discrepancies between experiment and theory. He points out that when the section of the water passages in the wheel enlarges, instead of decreasing from the interior outwards, there will be irregular eddying motion of the water in the passages of the wheel.

W. C. U.

Atmospheric Hammers.[2]

(Revue industrielle, vol. vii., p. 521.)

M. Chenot has designed a hammer, which has been constructed in various suitable forms by M. Golay, in which atmospheric

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[1] Civilingenieur, 1875, p. 49.

[2] For a description of Husband's pneumatic stamp, *vide* Proceedings of the Inst. Mech. Engineers, 1873, p. 143.

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air is employed as a spring for the purpose of accumulating and of applying the motive power. The hammer consists of a cylinder, turned from end to end. It is also bored throughout, but to two different diameters, that of the lower end being the smaller, and it is divided into two chambers, an upper and a lower, by a diaphragm fixed about midway of the cylinder. The lower end is thus completely inclosed, whilst the upper end is open. Two pistons, fixed to one rod passing through the diaphragm, play, the one in the upper and the other in the lower chambers, and they receive a reciprocating motion by means of a short connecting rod, from a crank overhead, driven by a band passed over a pulley fixed on the crank shaft. The cylindrical hammer is guided in a portion of the frame bored to receive it, and is at liberty for vertical movements according to the impulse which it receives from the air cushions or springs confined within it. These air cushions are three in number, one above the diaphragm, one below it, and the third below the lower piston. The hammer is thus floated on air; it is free from any solid attachments, and is impressed with a reciprocating movement, following the reciprocations of the pistons, by the agency of the cushions of air in its interior.

Suppose that the pistons make their up-stroke, the air above the lower piston is compressed against the diaphragm of the cylinder, whilst the air below each piston is rarefied; and the hammer is raised by the combined force of the compressed air and the external atmosphere. The hammer attains its maximum upward velocity just when the pistons, after having completed their up stroke, have attained their maximum downward velocity. A powerful reaction ensues, and the hammer is precipitated upon the anvil, and strikes the blow, even before the pistons have completed their down stroke. The height of the fall, and the force of the blow, are regulated by the speed at which the machine is driven. There is no heating of the working parts, and M. Chenot estimates that the efficiency of the machine amounts to 75 per cent. of the power communicated to the driving pulley.

For a hammer weighing 143 lbs. the hammer-cylinder is turned to a diameter of 7 inches, and is bored to $5\frac{3}{4}$ inches and 6 inches in diameter. The stroke of the pistons is $8\frac{3}{4}$ inches, and that of the hammer is 18 inches. The hammer is worked at from sixty to four hundred, or even six hundred, revolutions per minute, and is capable of forging, at ordinary heats, 4-inch square bars of iron, or $3\frac{1}{4}$-inch square steel bars. It is said that the hammer repays the outlay upon it in eighteen months. At a speed of sixty turns per minute, or one turn per second, the pistons can make their up-stroke in a half second. The hammer completes its up-stroke one-sixth second later; but, on the contrary, it overtakes and passes the pistons in the descent, makes the fall in one-tenth second, and rests on the iron only one-sixth second. By means of this machine, the workman is delivered from the paralysis of the arm (*casse-bras*) which arises from the labour of forging thin steel.

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According to another design, the driving power is derived from a steam cylinder, placed above the cylindrical hammer, and connected directly to the piston rod. By means of high speed and quick strokes, it is expected that this machine will displace the comparatively heavy hammers with long strokes.

D. K. C.

Machinery for Crushing Sugar-cane, and Expressing the Juice.[1]

By MM. MIGNON and ROUART.

(Revue industrielle, vol. vii., p. 509.)

This machinery was designed for the purpose of obtaining a greater percentage of juice from the sugar-cane than is yielded by the ordinary three-roller sugar-mill. It is found, by chemical analysis, that, in the cane, about 90 per cent. of its weight consists of juice; whereas the quantity extracted by the ordinary method does not exceed 68 per cent. The new machine (*défibreur de cannes*) is arranged on the principle of the machine made by the constructors for crushing straw into pulp for the manufacture of paper. The cane is reduced to a pulp, and, by subsequent pressure, 77 per cent. of juice is separated.

In the crushing machine, the cane is fed into a cast-iron cylinder 17 inches in diameter, where it is cut up by a series of double-pointed or triple-pointed cutters arranged helically and fixed on a horizontal revolving shaft. These co-operate, in the manner of shears, with three series of blades fixed to the interior surface of the cylinder, and by the combined action of the opposing series of blades, the cane is completely broken up, and is at the same time passed through the cylinder by the screw-like action of the revolving cutters. The pulp is discharged from the other end of the cylinder into a hydraulic press, where it is subjected to a pressure of 80 atmospheres, for the separation of the juice.

The press is constructed with a "differential piston," or plunger, of two diameters, $39\frac{3}{8}$ inches and 16 inches. The pressure is applied, first, to the smaller piston, the force of which is sufficient for expressing the greater portion of the juice. When the piston arrives within an inch or two from the end of its traverse, the pressure is applied to the annular area of the larger piston, in addition, when the "hard pinch," as it may be called, is applied to express the juice which remains in the pulp. The filter consists of three cylindrical receptacles, 20 inches in diameter, which are filled with pulp, and are presented in rotation to the ram, which is formed as a prolongation of the plunger. The receptacles are formed by a series of rectangular bars placed circularly and nearly

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[1] *Vide* "Recherches sur les jus de la canne à sucre," par Dr. E. Icery. 8vo. Paris, 1865.

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in contact with each other. Through the very small crevices between the bars, the juice is forced, whilst the bagasse or cake is dropped out below.

With these machines, when the crusher makes from thirty to forty turns per minute, from 30 to 60 tons of sugar-cane may be treated in a day of twenty-four hours. The machinery is in operation at Guadaloupe.

Work done by the Crusher.				Work done by the Press.			
Weight of Cane crushed.	Time of Operation.	Work in Twenty-four Hours.	Number of Revolutions of Crusher.	Weight of Cane pressed.	Time of Operation.	Weight of the Juice.	Density of Juice.
lbs.	Minutes.	Tons.		lbs.	Minutes.	lbs.	°
220	5	28·6	30	220	6	154	10·00
220	4	35·8	30	220	6	160	10·00
440	7	40·7	30	661	12 to 15	500	7·50
2,645	30	57·3	40	693	„	528	8·75
881	11	52·0	35	168	„	253	10·00
1,322	14½	58·5	40	440	„	338	8·00

The machinery sent to Guadaloupe can crush 59 tons of cane per day. Simply crushed and submitted to one pressing the cane has yielded 77 per cent. of its weight, in very rich juice. The bagasse when crushed yields 25 per cent. of its weight, in very rich juice.

D. K. C.

On the Production of Compressed Fuel from Earthy Lignite in Prussia. By R. A. Schultz.

(Zeitschrift für Berg- Hütten- und Salinenwesen, vol. xxiv., p. 234.)

The lignite of the North German plain, when freshly raised, generally breaks up to dust and slack on drying; and the economic value of such a material being small, the greater portion of the produce of the lignite mines was left upon the waste heaps, or even underground. The rapid increase in the prices of better descriptions of fuel has, however, led to the adoption of various methods of compressing the slack with a view of obtaining coherent masses that can be burnt in an ordinary grate.

Wet Coal Pressing Machines.—After being finely divided by passing through rollers, the coal is mixed to a uniform paste, and moulded by pressure through a die-plate or mouthpiece of rectangular section, whence it passes out in a continuous stream, and is cut into pieces of the proper size by a frame carrying strained steel wires. To prevent the coaly mass from adhering to the cast-iron die-plate, Herr Schmelzer of Magdeburg substituted for the original cast-iron die a slightly conical mouthpiece in bronze or

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copper, with hollow sides, which is kept heated to about 212° Fahr. by a current of waste steam from the engine driving the press. These machines are made in three sizes, the smallest producing twelve thousand, the middle size twenty thousand, and the largest up to forty thousand blocks per shift of ten hours. Pressed blocks have a heating power about 11 per cent. greater than those moulded by hand; but it is found better not to push the drying too far, as the best effect is got with blocks containing 40 or 41 per cent. of water, which stand the fire better, and do not break up and pass through the bars unconsumed. The cost of production of thirty-five thousand blocks daily is about £4 10*s.*, or 2*s.* 7*d.* per thousand for wages, and from 2*s.* 9*d.* to 4*s.* 7*d.* for the coal; the average selling prices are from 11*s.* to 14*s.* per hundred.

Dry Coal Pressing Machines.—The process is based upon the property possessed by the earthy brown coals of becoming coherent under pressure when finely powdered and completely deprived of hygroscopic water.[1] The coal is passed over sieves of from 5 to 10-millimètre mesh, and when not sufficiently small, it is passed through crushing rollers.

The drying in ovens is the most difficult part of the process. The oven consists of ten hollow steam-heated horizontal discs, of wrought iron, 12 feet in diameter, placed parallel to each other, at vertical distances of 17·7 inches apart, so that the total height is from 16½ to 18 feet. It is usually heated by waste steam from the engines, so that the temperature attained is rarely above 176° Fahr. The coal is kept in the oven for about fifty minutes, retaining from 25 to 30 per cent. of water, and must be passed through a second time before it is fit for pressing, a circumstance which sufficiently accounts for the small amount of work done, namely, 512 cubic feet of coal dried in the twelve-hour shift, or about half the quantity required to keep a press employed during the same time.

Jacoby's tubular oven, in which the distribution of the wet coal is effected by gravitation, consists of twelve parallel horizontal pipes, united at regular vertical intervals by outside bands into a coil similar to that of the Westphalian hot-blast stove. The pipes present a central ridge along the axis of the oven, upon which the coal, fed in by a hopper, falls, and is diverted onwards, to be received in a second hopper below, which distributes in the same way upon the ridge of the next pipe below, and so on to the bottom. Although there are no moving parts, and the feed is automatic, the first cost is large (from £3,500 to £4,000); this and other steam-heated stoves have been abandoned in favour of those worked by heated gases. Riebeck's gas oven is similar in form to the steam disc oven previously described. Originally

[1] This property is analogous to that of the asphaltic limestones of Savoy and Switzerland, which disintegrate when heated, but can be completely consolidated by subjecting the powder to a moderate pressure at a temperature of 130°.—H. B.

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twenty-one plates were used in each oven; but they are now generally made with only twelve or fifteen. The outside diameter of the disc is about 13 feet, and their vertical distance about 12 feet. The whole apparatus is inclosed in a rectangular chamber of brickwork, which is maintained at a uniform temperature of about 260° by a current of heated gases from a special fire-place, entering at 400° to 450°, and leaving the chamber at 100° or 150°. The coal containing 45 per cent. of water is dried to 15 per cent. by one hour's exposure. This, together with the small first cost of £450 and the moderate consumption of fuel, has led to the general adoption of this oven, although small repairs are difficult, and there is danger of the coal firing, or becoming useless through overheating.

In Leutert's chamber oven, the coal is dried by passing it downward in a thin stream through a heated chamber; the distribution being effected by a series of angle-iron spreaders, resembling ladders with inclined steps or louvre-board ventilators. The apparatus consists of a rectangular block of brickwork about 28 feet long, 26 feet broad, and 25 feet high, divided by internal walls into four oblong chambers, each of which contains four pairs of spreading-bars or ladders. The interior of the chamber is maintained by fire gases at 180° or 200°. The consumption of fuel in drying varies with the different classes of oven, being greatest in the trough ovens, which burn about 11 per cent. of the volume of coal dried; while in the disc and chamber ovens it averages about 8 per cent. In all these ovens great care has to be taken to exclude atmospheric air, as otherwise the coal begins to smoulder, sets free explosive gases, and imperils the working.

The modified Exter press used for moulding the oven-dried coal into blocks is a horizontal reciprocating plunger moving in a steel-lined press tube. The press makes sixty strokes per minute, producing an equal number of blocks. A single press in the shift of twelve or ten working hours can make thirty-six thousand. The coal is reduced in the finished product 56·5 per cent. in volume, and 33½ per cent. in weight. As, however, 18 to 20 per cent. of water is retained, only 26 per cent. of the above amount represents the actual evaporation, the remaining 7½ per cent. being lost by decomposition, through heating, and as dust and breakage in the pressing. The specific gravity of the pressed blocks is 1·20 to 1·22, or somewhat less than that of natural air-dried lignite. They are very solid, and bear transit without breaking, being especially in demand for domestic purposes; the selling price is about 6*s.* or 6*s.* 6*d.* per thousand.

The cost of a well-arranged press and drying oven with the necessary engines and boilers is at least £6,000, corresponding, at 10 per cent., to a charge for sinking fund and interest of £2 per working day, or £1 per thirty-six thousand blocks produced. The cost for labour, fuel, and management brings up the producing price of the above quantity to £3 2*s.*, or about 1*s.* 10*d.* per thousand, to which must be added the cost of 21 bushels of slack.

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The general properties of the different classes of fuel previously described are summed up in the following table:—

—	Wet Coal as raised.	Hand-moulded Blocks.	Wet-pressed Blocks.	Dry-pressed Blocks.
Specific gravity . .	1·22— 1·29	1·24— 1·31	1·26— 1·32	1·20— 1·22
Proportion of water, per cent. . . .	42·30—47·00	32·10—35·40	26·60—30·00	17·20—21·50
Proportion of ash, per cent. . . .	6·00— 9·30	7·70—13·80	8·60—10·50	10·00—14·20
Heating power . .	183—209	179—223	231—287	254—315
Cohesive[1] „ . .	..	0·17— 0·22	0·38— 0·45	0·68— 0·74
Condensation in volume, per cent. .	..	36·4	50·1	56·6
Value per 1 hectolitre of coal . .	*d.* *d.* 1½—2½	*d.* *d.* 3—3½	*d.* *d.* 4½—6½	*d.* *d.* 6¾—7½

Of the two classes of blocks, the wet-pressed are in somewhat larger demand, which the Author attributes to their being comparatively cheaper for an equal amount of useful coal than the dry-pressed; 1 ton of useful coal, *i.e.* after deducting that required for the evaporation of the contained water, costing 17*s.* 2½*d.* in the former, and 25*s.* 5*d.* in the latter class. The Author considers, however, that the manufacture is still susceptible of considerable development, both in the direction of improvement of produce and reduction of price.

H. B.

On the Manufacture of White Forge Pig Iron from the Oolitic Iron Ores of Luxemburg. By J. WOLTERS.

(Annuaire de l'Association des Ingénieurs sortis de l'École de Liége, vol v., pp. 1 and 104.)

This is an investigation of the working of a blast furnace making white forge pig iron from the minettes or oolitic ores of Luxemburg. The data made use of are stated to be the mean of six consecutive days' working of the furnace; but no information is given as to the locality of the particular furnace under consideration, the methods of analysis adopted, or the precautions taken to obtain a fair average sample of the escaping gases and to determine accurately their mean temperature.

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[1] The proportion of unbroken fragments remaining after subjecting a weighed quantity to fifty revolutions in a rotating cylinder.

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The furnace was 49·2 feet in height, 16·4 feet in diameter at the boshes and 4·3 feet at the hearth, and produced 46 tons of pig iron per twenty-four hours, equal to 118 cubic feet of internal capacity per ton of pig iron made. The ore smelted contained 30·32 per cent. of iron (the average yield of the ores of the district being about 33 per cent.), the temperature of the blast was 370° Fahr., and the consumption of coke (containing 12·6 per cent. of ash and 5·5 of water) was 1,191 lbs. per 1,000 lbs. of pig iron made. Full analyses are given of the mixture of ores used, the coke, the limestone, the pig iron produced, the cinder, the escaping gases, and the dust carried away by the gas and deposited in the flues. The ore contained in itself so large a proportion of lime that, to produce a cinder containing 33·5 per cent., only 28·6 lbs. of limestone were added to the charge of 54 cwt. of ore, and 19·5 cwt. of coke. The dust deposited in the flues amounted to 35 lbs. per ton of pig iron made, and contained 39·6 per cent. of iron.

After calculating (from the composition of the materials charged into the furnace) the quantity of cinder produced and the quantity of water and carbonic acid contained in the charge, per ton of pig iron made, the Author passes to the consideration of the economic conditions under which a furnace treating minettes works, and points out that in the furnace in question the ratio of $\frac{CO_2}{CO}$ in the escaping gases, the measure of the degree of perfection of the economic working of a blast furnace, is greater than it is, as given in Mr. Bell's Papers, in the best furnaces in Cleveland. In this furnace, the ratio of $\frac{CO^2}{CO}$ in the gases is (by weight) 0·853, equivalent to 35·2 per cent. of the total carbon in the gases in the form of CO_2, and 64·8 per cent. in the form of CO. In the Cleveland furnace compared with it, the ratio is 0·673, equivalent to 30 per cent. of the total carbon in the gases as CO_2 and 70 per cent. as CO. It is true that the charge of the furnace working minettes contains a slightly larger proportion of carbonates than that of the Cleveland furnace; but deducting in each case the proportion of CO_2 given off from these, the former furnace still shows the better economic result; the ratio between the CO_2 and the CO, *produced by combustion*, being in its case 0·672, corresponding to 30 per cent. of the carbon, in the products of combustion, in the form of CO_2; and in the case of the Cleveland furnace 0·518, corresponding to only 24·8 per cent. of the carbon burned to CO_2.

It may be assumed that a better combustion of the carbon than this would be, if not unattainable, at least very difficult to realise in practice; and the advantages to be looked for from an increase in the height of the furnace, or from a higher temperature of blast, are thus much limited.

In general, an increase in the height of a blast furnace lowers

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the temperature of the escaping gases, and, by adding to the volume of the region of reduction, promotes the dissociation of carbonic oxide and so renders the gas richer in carbonic acid. It is assumed, however, as above, that a greater richness in carbonic acid than that already reached in the furnace under consideration cannot be practically attained; and as, at the same time, the temperature of the escaping gases is now less than 392° Fahr., owing to the large proportion of carbonic acid and water in the charge, comparatively little advantage is to be looked for from such further cooling of them as might result from a greater height of furnace.

The effects of hotter blast, in addition to the mere substitution of blast heat for the heat of combustion, are precisely the same as those of an increased height of furnace; but, as already pointed out, little advantage is to be looked for, in the case of the furnace in question, from any practicable increase in the ratio of $\frac{CO_2}{CO}$, or decrease in the temperature of the escaping gases; and hence the chief source of economy in giving a higher heat to the blast will be the substitution of the units of heat carried in by it for an equal number that would otherwise have to be supplied by direct combustion within the furnace itself. There will thus be no advantage in heating the blast more highly, unless in so far as this can be done solely by the combustion of gases that would otherwise be wasted.

The amount of heat that the gases are capable of giving off, when burned, is somewhat greater than that evolved, in the furnace itself, by the direct combustion of the fuel; and if the hot-blast apparatus and the blowing arrangements are in good order, no other combustible need be used.

If coal were employed to supply the needed power for working the blowing engine, the lift, and the pumps, the quantity that would be required for these purposes may be estimated, under good arrangements, at 12 tons per day, equivalent in heating power to 156,429 kilogrammes of the furnace gas. The total quantity of gas produced in the same time being 321,570 kilogrammes, 165,141 kilogrammes will be left for heating the blast, supposing that the furnace is worked with a closed top, so that all the gas it gives off may be collected. Assuming again that the hot-blast apparatus, whether of cast iron or of fire-brick, is so constructed as to transfer to the air 50 per cent. of the heat evolved by the gas burned in it, this amount is sufficient to heat the blast to 1,522° Fahr. Hence, if half of the escaping gas is collected and economically utilised, it will be sufficient to work the blowing engine, the lift, and the pumps; if two-thirds are collected, the blast may, at the same time, be heated, without the use of any other combustible, to a moderate temperature (about 572° Fahr.), and if all is made use of, it may be readily heated to the highest temperatures that have yet been reached in practice.

Owing to the comparative poverty of the gas in carbonic oxide, and to the large amount of water that it contains, the theoretical

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temperature that may be produced by its combustion is considerably less than in the gases of Cleveland furnaces, of which analyses are given in the Papers of Mr. Bell and M. Grüner. It is only 2,411° Fahr. for the gas in its actual moist state, or 2,588° Fahr. if calculated as for gas perfectly dry; whereas in the case of the gases from the Cleveland furnaces, treating calcined ore, the lowest theoretical temperature of combustion is 2,696° Fahr. and the highest 2,978° Fahr. Thus it is more easy to heat the blast to very high temperatures in the case of the Cleveland furnaces than in that of furnaces working minettes.

The calculation of the quantities of heat received and consumed by the furnace is worked out in considerable detail; and the Author then passes to a further consideration of the economy to be looked for from increasing the temperature of the blast; it being assumed, as above, that to whatever temperature this may be raised, the ratio between the amounts of CO_2 and CO, produced by combustion, remains the same. The temperature of the gases, corresponding to a blast temperature of 370° Fahr., being 356° Fahr., it is further assumed that if the blast were heated to 1,832° Fahr. the temperature of the gases would be only 212° Fahr.; the temperature of the furnace throat falling, in arithmetical progression, as that of the blast is raised.

Combining these assumed data with the known conditions of the working of the furnace, the calculation of the amounts of heat that are respectively received and expended in it is repeated, expressing each in terms of the blast temperature and the quantity of carbon consumed; and by equating the two totals, an expression is obtained for the weight of carbon consumed, per ton of pig iron made, as a function of the temperature of blast employed. Substituting in this expression a series of blast temperatures rising from 370° Fahr. to 1,832° Fahr. (from 188° to 1,000° cent.) the corresponding consumptions of coke are calculated. From this it appears that under the assumed conditions each rise in the temperature of the blast would be accompanied by a saving in coke, which would decrease, however, from 96·8 lbs. per ton of pig iron made, for the rise from 392° Fahr. to 572° Fahr. (from 200° to 300° cent.) to 61·6 lbs. per ton, for the rise from 1,292° Fahr. to 1,472° Fahr. (from 700° to 800° cent.); the consumption, with blast at the latter temperature (to which it may be raised without the use of any other fuel than the furnace gases), being 19 cwt. 25 lbs.; an economy of 4 cwt. 23 lbs.

In the second part of the Paper the Author discusses the extent to which the proportions of coke, ore, and limestone must be altered, to maintain the furnace in the same working condition, when ores differing in composition or in richness are employed, or when the coke used is more or less dense, or contains an excessive proportion of ash or water.

W. H.

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Calorimetric Researches on the Carbides and Silicides of Iron and Manganese. By MM. L. Troost and P. Hautefeuille.

(Annales de Chimie et de Physique, vol. ix., p. 56.)

Amongst other subjects treated in this Paper are the following notes upon the function of manganese in metallurgy.

It may be thought, from numerous calorimetric experiments, that the manganese employed in the treatment of impure irons combines with the foreign matter, and that these combinations dissolved or disseminated in the metallic mass facilitate its purification by communicating to the elements to be eliminated the "oxidability" requisite for the corresponding compounds of manganese. This is often so; but manganese has also the more simple function of reducing the oxide of iron. Indeed, in several metallurgic operations, the elimination of the sulphur or phosphorus necessitates a prolonged oxidation, which furnishes a metal intimately incorporated with oxide of iron. The addition of a ferromanganese compound, always very rich in carbon, restores to the metal the carbon it should contain, and reduces, with disengagement of heat, the oxide of iron at the same time by its carbon and by its manganese. The oxide of manganese formed and disseminated in the metal does not present the same inconvenience as oxide of iron, for it passes almost immediately into the scoriæ, carrying with it some impurities. The importance of manganese in the metallurgy of iron is due to (1) the formation of compounds which are produced with disengagement of heat greater than that from the compounds of iron; (2) the easy scorification of these compounds. Independently of these results, the Authors' calorimetric determinations allow them to establish that the carbides of iron are constituted with absorption of heat; that the manganese and carbon disengage much heat in their union, and that in this relation the carbide of manganese, Mn^3C, is comparable with the more stable compounds of mineral chemistry; that combination of manganese with iron and carbon is also accompanied with great disengagement of heat, and that, consequently, the ferromanganeses are true combinations; that silicium unites with the manganese with disengagement of much heat, and consequently forms, with this metal, combinations as stable as those formed with carbon; that the comparison of the two metalloids, carbon and silicium, may be continued when their action on iron is considered, as both then appear to be dissolved in this metal.

P. H.

Disengagement of Ammonia in Rupture of Steel. By M. Barré.

(Comptes rendus de l'Académie des Sciences, vol. lxxxiii., p. 1178.)

The Author has previously drawn attention to the disengagement of ammonia produced by rupture of a steel rail. M. Daubrée

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advised the verification of this phenomenon by means of test papers. Two ends of steel rails were broken off, the steels being of different hardness; the test papers applied to the broken surface wetted, changed colour. Bubbles of gas issued from the moistened surface for a quarter of an hour. With steel of less hardness submitted to the same trials the disengagement of ammonia was less sensible, but the action on test papers was decided.

The preceding observations apply to steel manufactured in gas furnaces by the Siemens process, but it has been noticed by several engineers, when breaking Bessemer steel rails in testing, that there was a decided odour of ammonia.

P. H.

On the Influence of Temperature on the Specific Heat of Mercury.

By A. WINKELMANN.

(Poggendorff's Annalen der Physik und Chemie, vol. clix., p. 152.)

The Author, in his experiments, found the unexpected result that the specific heat of mercury diminishes as the temperature rises.

The calorimeter employed was a cylinder of thin plate iron resting on three ivory feet, and containing mercury, placed in a double cylindrical casing of similar material filled with water. The mercury experimented on was heated in a bath, from which it was removed by means of a bucket of thin iron. Its weight, that of the calorimeter, of a paddle for stirring, and of the bucket being known, the quantity of hot mercury introduced into the calorimeter was always calculable. It was important that the transference of heat should be as quick as possible, and it was found that 98 per cent. of the total rise of temperature in the calorimeter took place in the first ten seconds.

There were two series of experiments, which differed both in the temperature to which the mercury was in the first instance raised and in the quantity which was removed to the calorimeter. The variation in the specific heat of iron which affected the "water value" of the calorimeter was calculated from Bède's formula

$$C_t = 0{\cdot}1053 + 0{\cdot}000071\, t.$$

The value of the specific heat of the mercury in the calorimeter was taken, after Regnault, at 0·0333.

In the first series of experiments the weight of mercury removed was only about 58 grammes, and it was raised only to a temperature, first, of about 122° Fahr. (50° centigrade), and afterwards of 285° to 298° Fahr. (141° to 148° centigrade). At the lower temperatures the mean of four experiments gave 0·03308 as the specific heat, at the higher a first mean of five experiments gave 0·03265, and another mean of five experiments gave 0·03261. In the second series the weight of mercury removed was about 110 to 112 grammes, and the temperatures were approximately the

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same as in the first series. At the lower temperature the mean of five experiments gave 0·03309, and at the higher 0·0326. Both series gave accordant results, the maximum variation between any experiment and the mean was 0·6 per cent.

The number 0·03308 gave the mean specific heat between 122° Fahr. and 64° Fahr. (50° and 18° centigrade), and 0·03262 that between 291° Fahr. and 75° Fahr. (144° and 24° centigrade). Then

$$c\,t = c_o + a\,t;$$

and $c_o = 0·03339$ and $a = -0·0000092$.

Thus at 212° Fahr. (100° centigrade) the specific heat is about 3 per cent. less than at 32° Fahr. (0° centigrade). The above value of c_o cannot be exact, as the variation of the specific heat of iron with temperature is not exactly determined.

E. B.

On the Reduction of Silver Ores by the Californian Method in Mexico. By H. Richter.

(Zeitschrift für Berg- Hütten- und Salinenwesen, vol. xxiv., p. 264.)

The ores raised at the Tajo mine at Rosario, near Mazatlan, are essentially mixtures of quartz with argentic sulphide, and probably some silver and gold, together with some galena brown blende and pyritic minerals; the average contents of silver being 40 oz., and of gold 2¾ oz. per ton, with from 6 to 8 per cent. of lead and zinc. The reduction is effected by the American method of pan amalgamation without previous roasting. The ore is partially divided, by hand-picking, into rich and poor classes, without, however, attempting to remove any of the lead or zinc minerals, which are passed by a mill of twenty stamper-heads, with rotating lifters weighing 7 cwt. and making sixty 9-inch strokes per minute, through grates having apertures ½ inch in diameter, 24 tons being stamped daily. The slimes pass first into a pit 3·3 feet deep and 9·8 feet in cross section, where the richer material forming the normal ore for the pans is deposited, after which a second collection of poorer stuff is made in a second pit of the same size, and finally the waste, together with that from the pans, is passed through a series of catch-pits 9·8 feet long, 5 feet broad, and 3·3 feet deep.

The reduction of the richer slimes is effected in pan amalgamaters of the improved Varney pattern,[1] which perform the three operations of grinding the particles of ore to impalpable mud, mixing the particles with the chloridising agent, and reducing

[1] *Vide* "Elements of Metallurgy," by J. A. Phillips, p. 650 *et seq.* Also Hague and King's "Mines of Nevada," and Raymond's Reports, &c.

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and amalgamating the silver minerals. The pan is essentially a mill, with cast-iron instead of stone grinding surfaces, which is adopted partly from economy and partly from the property possessed by iron of reducing the mercurial chlorides. These surfaces are put together in segments, so as to be easily renewable, as they are worn out in forty days when worked at seventy revolutions per minute. The charge of the pans is 800 lbs. of ore stuff from the stamps, which is mixed into a thin mud by adding water and running the pan for half an hour or an hour until the materials are sufficiently ground. During this period a jet of steam is introduced in order to warm up the contents to 176° Fahr. Chloridising and reducing agents are then added in the following proportions—sulphate of copper 4 lbs., salt 40 lbs., and mercury from 70 to 90 lbs., including $\frac{1}{4}$ lb. of zinc amalgam, or about thirteen times as much salt and thirty-two times as much mercury as is used in the Mexican or "patio" process of amalgamation. The copper salt is added in somewhat larger quantity than would be required for the chlorination of the whole of the silver, assuming it to be effected by cupric chloride. The reactions are considered by the Author to be substantially the same as those in the "patio" process, and as probably occurring in the following order: amalgamation of metallic silver and gold; conversion of cupric sulphate into chloride; conversion of silver sulphide by cupric chloride, with the formation of cuprous chloride, into silver chloride; reduction and amalgamation of the latter by metallic mercury; and, finally, decomposition of the mercurial chlorides formed by the iron of the pan. The zinc amalgam is said to help by the production of electric currents. Like the Mexican process, the method is not well suited for the treatment of minerals containing lead, zinc, or antimony, the working of such ores being attended with a considerable loss of silver and mercury.

The amalgamation process proper requires about four hours, the progress of the operation being controlled by washing out samples of the mud at intervals, and observing the colour and form of the mercury globule obtained, which should be grey, and "tail," or assume an oval form.

The finished charge from the pan is received in a cylindrical washing vat, or settler, and allowed to rest for an hour, whereby the bulk of the mercury and amalgam separate from the mud and fall to the bottom. Afterwards the lighter particles are removed through a hole in the side by a stream of water, which flows for fifty minutes; lastly, the bulk of the mercury is separated from the remaining heavy mud charged with ore, by drawing it from a lower opening for ten minutes. As the amalgam is very poor, owing to the large quantity of mercury used, only the excess of the latter introduced at each washing above a large fixed amount is removed in clearing the settler, the whole quantity being only removed at intervals of eight days.

The waste or tailings of the first operation, consisting largely of heavy metallic sulphides, with probably some silver-sulphide, and

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containing about 35 per cent. of the original amount of silver, are reworked in four large pans or "tailing mills," which take charges of double the weight of those worked in the ore-pans, but are otherwise similarly arranged. An assay of this material gave 28 oz. of silver per ton, and appeared by vanning to consist of $\frac{9}{10}$ of quartz and $\frac{1}{10}$ of heavy sulphides, pyrites, blende, and galena. The reagents used per 1,600-lb. charge are, salt 40 lbs., sulphate of copper 5½ lbs., and mercury 120 lbs., the latter being about seventy times the weight of the silver in the ore.

The working of the tailings both in the pans and settlers is exactly similar to that in the ore mills. The waste from the last washing, containing about 1 oz. to the ton, is passed through a catch-pit before being allowed to run to waste. A further quantity of 20 per cent. of silver is recovered by the second operation, showing the final loss to be about 15 per cent. of that contained in the ore. Allowing four hours for the filling of the tailing tanks, the extraction of the silver from the ore, counting from the first charging of the ore-pan, is effected in sixteen hours. The amalgam collected is treated at intervals by filtration through canvas, after which it is washed in quantities of a few cwts. at a time in a pan with water to clear it from mechanical impurities, filtered a second time, and finally heated in retorts holding 1,200 lbs. The time required for distillation is from eight to fifteen hours, on account of the great variability in its composition. The sponge silver for the retorts is melted in blacklead crucibles holding 50 lbs., and run into bars.

The great advantage of the pan process, as compared with other metallurgical operations, namely, speed and cheapness of work, together with large production from a small plant, are, in the Author's opinion, obtained by a considerable waste of silver, which he calculates at 18·7 per cent. of the total quantity, and as due to the effect of the lead and zinc ore. Nearly the whole of the gold is, however, saved. The loss of mercury is 2 lbs. per 2,000 lbs. of ore treated, or 80 per cent. of the weight of the silver. The staff required is very small. With twelve workmen of all descriptions about 17 tons of ore are treated per day. The machinery is driven by steam power, the cost of wood for two engines being about £8 daily. The total cost of working, including wages, materials, wear of machinery, &c., is about £2 per ton of ore treated, or about 1*s.* 2*d.* per oz. of silver recovered.

H. B.

On the Treatment of Argentiferous Zinc in North America.

By Dr. H. Wedding.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, vol. xxiv., p. 469.)

The desilverisation of lead by means of zinc (Parkes' process) has of late years been very generally adopted. The chief difficulty

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of the process has been in the recovery of the silver from the zinc, as although the latter can be separated by distillation, the presence of lead in the alloy exercises a very destructive influence upon the retorts used in the separation. A method introduced by the Author at Tarnowitz,[1] which consists essentially in providing the retorts with a carbonaceous lining, although well suited to the particular locality on account of the large supply of zinciferous materials available for reduction, in addition to the metal actually used in desilverising, has not proved to be practically available in the Harz, partly from the latter cause, but more particularly from the high price of fuel, which prevents the use of the large furnaces adopted in Silesia.

The Author's attention having been directed to the American modification of this process, he proceeded to examine it as carried out at Newark in New Jersey, Pittsburg, and St. Louis. It consists in the substitution of a retort made of a refractory mixture of fire-clay with a considerable amount of graphite for the carbon-lined clay muffle. This being of a pear-shaped form, can be turned partly round after each operation so as to bring a fresh surface in contact with the molten lead, whereby uniform wear is promoted.

The argentiferous zinc, after being drained as carefully as possible from adherent lead, is mixed with carbon and charged into the retorts. Each of these is placed in a separate wind furnace, filled with coke, so that the retort is heated by direct contact with the fuel, from six to eight furnaces being connected with the same stack. The zinc is collected in a receiver made out of an old retort. When the distillation is ended the whole furnace is lifted and tipped forward by a simple mechanical arrangement, and the residual lead, containing the whole of the silver, flows out of the neck into a mould or collecting ladle placed to receive it.

The general outline of the process as followed at Newark is as follows:—

The original ore furnace lead (*a*), which is very impure, containing, in addition to silver, antimony and copper in notable quantities, is first refined in an improving furnace. The products of this operation are softened lead (*b*), free from antimony, and first antimonial dross (*c*). The latter material, when reduced with lime and coal dust, gives up some lead (*b*), which is added to the original lead (*a*), and a residue, which is reduced to antimonial or hard lead for sale.

The softened lead (*b*) is charged in pigs into a furnace where it is liquated at a low heat, producing a very pure argentiferous lead (*f*), and a coppery dross, which, with other materials of a similar kind, is smelted for copper regulus, reduced to metallic copper, and ultimately converted into blue vitriol, when any silver that it may contain is recovered from the insoluble residue.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xl., p. 340.

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The soft lead (*f*) is melted and treated with about 1½ per cent. of its weight of zinc (*z*) in the usual way; the argentiferous zinc crusts (*g*), after separation, being subjected to liquation, which removes a certain amount of lead (*h*) still notably argentiferous. The liquated zinc crust is then subjected to distillation in the manner described, producing metallic zinc (*y*), which is returned to the desilvering pots, while the rich argentiferous lead is refined by cupellation, producing metallic silver and argentiferous litharge.

The drained lead (*h*), subjected to a second treatment with about ½ per cent. by weight of zinc, which removes the residual silver as far as it is possible to do, and after treatment in an improving furnace to get rid of the last traces of zinc, is fit for sale as soft pig lead. The skimmings of this second operation not being sufficiently rich in silver to be immediately distilled are used several times over in the treatment of fresh quantities of lead.

The process, as described in the preceding paragraphs, has been recently introduced into the smelting works at Altenau in the Harz, and is apparently well suited to the locality, judging from the favourable results obtained in the first experiments. The retorts which were made in Dusseldorf could be used ten times before they became perforated, and comparative trials of these against retorts made in America are now in progress.

In conclusion the Author points out that the same process had also been tried at the smelting works of Mechernich in the Eifel, and that the results obtained there had been placed at his disposal.

H. B.

On the Recovery of Sulphur from Gypsum and Sulphate of Soda in the Manufacture of Glass. By DR. O. SCHOTT.

(Dingler's Polytechnisches Journal, vol. ccxxi., p. 142.)

After pointing out the desirability of saving the sulphur present in the sulphate of sodium used in the manufacture of glass, the Author directs attention to an equation which he had previously given for the reaction between sulphate of sodium, carbon, and silica:—

$$2Na_2SO_4 + C + 2SiO_2 = 2Na_2SiO_3 + 2SO_2 + CO_2$$

The practical difficulty of the method of recovering the sulphurous acid indicated by this reaction has been such as to prevent the attempt; for even if the melted silicate of sodium could be prevented from attacking the walls of the furnace, the cost of fuel, &c., would be such as to outweigh the value of the recovered sulphur. Convinced that the recovery of sulphur from sulphate of sodium alone is not sufficiently remunerative, the Author endeavours to remedy this defect in glass manufacture by using, instead of silicate of sodium, a silicate of sodium and calcium got by heating a

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mixture of sulphate of sodium, gypsum, carbon, and silica. By the introduction of lime, as gypsum, with excess of carbon the Author has easily succeeded in melting the sulphate of calcium into glass. In order that the expulsion of the sulphur should be complete it is not necessary that both silicates should be wholly fused. The incompleteness of the fusion, as well as the presence of the silicate of calcium, tends greatly to prevent the walls of the containing vessel from being attacked, as they would be by silicate of sodium alone.

The Author proceeds to show that the amount of gas developed is more than sufficient to insure homogeneity. Out of a charge weighing 8,058 lbs. the weight of sulphurous and carbonic acid gases given off is 1,861 lbs., giving a volume (at 32° Fahr. and 29·92 inches of pressure) of 12,855 cubic feet, and this at the temperature of the furnace will be increased to about 35,300 cubic feet, which is greatly in excess of what is required to prevent streakiness. To avoid this danger care must be taken either to leave enough gas in the crude glass during the interruption of the operation, or to add to the crude glass (if wholly free of gas) a small quantity of the crude material of charge.

In the Author's experiments the gas given off consisted of 2 volumes of sulphurous acid and 1 volume of carbonic acid. If the presence of the carbonic acid is found to interfere with the action of the gases in the leaden chambers, a sulphide may be used in place of carbon as a reducing agent, when sulphurous acid alone will be given off. The mischief done by sulphurous acid gas in the neighbourhood of a glass-work is such as to make the saving of the sulphurous acid highly advantageous to the district as well as profitable to the proprietor. The price of the gypsum need not amount to much more than that of the chalk or lime now used. The expense of the recovery of sulphur, in fuel and labour, will be more than covered by the value of the sulphurous acid. Although the process had not yet been fully tried, the Author believes that it possesses the following advantages: the absence of free alkali will increase the safety of the crucibles, the time of melting will be shortened, and the damage to the alkali will be reduced to a minimum.

J. A. E.

Temperature of Explosion of Dynamite. By PHILIPP HESS.

(Dingler's Polytechnisches Journal, vol. ccxxi., p. 548.)

Experiments made at intervals during the year 1876 by the Technical and Administrative Military Committee at Vienna, under the superintendence of the Author, have led to some important practical results relative to the explosion of various compounds used for blasting purposes. It was found that, when dynamite was exploded by the fall of a weight upon it, the height through which the weight fell had to be increased as the temperature of the

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compound was lowered. This fact—which might, indeed, have been foreseen—proves the comparative safety of frozen dynamite. The experiments undertaken to determine the temperature of explosion fully confirm the conclusion arrived at by M. Champion—that nitroglycerine compounds, when gradually heated, explode at a much lower temperature than when they are suddenly brought into contact with highly heated bodies. The following are the results arrived at by the Military Committee:—

	Temperature of Explosion.		Relative Force of Blow required to cause Explosion.	
	When slowly heated.	When suddenly heated.	In a plastic state, 72°.	Frozen.
	°	°		
Common blasting powder . .	..	From 500 to 540	7·75	..
Abel's gun-cotton	360	482	..	..
Kieselguhr dynamite of 50 per cent. nitroglycerine . . .	356	446	..	..
Kieselguhr dynamite of 70·5 per cent. nitroglycerine . .	356	446	0·75	1·00
Kieselguhr dynamite of 72 per cent. nitroglycerine . . .	356	446	0·75	1·00
Gun-cotton dynamite . . .	345	442	0·50	1·25
Cellulose dynamite, A quality .	342	446	1·50	1·75
" B " .	336	446	1·25	1·75

In these experiments, the gradual heating of the explosive compound was commenced at 140° Fahr. The method adopted was to drop small quantities of the substance to be tried into a glass "éprouvette" placed in a bath of melted paraffin, in which a thermometer was set.

G. G. A.

Volatility of Nitroglycerine in Dynamite. By PHILIPP HESS.

(Mittheilungen über Gegenstände des Artillerie- und Genie-Wesens, 1876, pp. 117–119.)

At a temperature of 158° Fahr., several grammes of nitroglycerine will disappear in a few days if exposed in thin layers in watch-glasses. But nitroglycerine is volatile at ordinary temperatures also, and it is probable that the constant loss of the active principle in dynamite, due to this cause under the ordinary conditions of storage, diminishes in course of time, in an important degree, the power of that explosive. In order to ascertain the amount of loss which takes place, the Author made some experiments on dynamite manufactured in the years 1871 and 1872. From 40 to 50 grammes of the material were placed in glasses, lightly closed, so that any gases disengaged might readily escape, and put aside till September 1876. During this time the dynamite

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was exposed to variations of temperature ranging between 50° and 75° Fahr. The analyses made in 1871 and 1872, and again in 1876, appear as follows:—

DYNAMITE of 1871.

	1871.	1876.
Nitroglycerine	72·98	69·36
Kieselguhr	27·02	28·64
Moisture	..	1·80
	100·00	99·80

Or, neglecting the water, which was not taken into account in the analysis of 1871,

	1871.	1876.
Nitroglycerine	72·98	70·78
Kieselguhr	27·02	29·22

DYNAMITE of 1872.

	1872.	1876.
Nitroglycerine	71·71	70·30
Kieselguhr	26·99	27·56
Moisture	1·35	1·65
	100·05	99·51

Or, neglecting the water,

	1872.	1876.
Nitroglycerine	72·63	71·11
Kieselguhr	27·37	28·89

Thus it appears that, in five years, the sample of 1871 lost 2·20 per cent.; and that of 1872, in four years, lost 1·52 per cent. of nitroglycerine.

It is admitted that these results may be largely modified by methods of manufacture, packing, and storage; but it is clear that dynamite, freely exposed to the air, must in course of time lose an important percentage of its active principle. The Author suggests that, to avoid this weakening of the dynamite, the supply should be so regulated by the consumption that the store should not remain long on hand.

G. G. A.

Practical Method for Trial of Batteries. By M. LECLANCHÉ.

(Comptes rendus de l'Académie des Sciences, vol. lxxxiii., p. 1236.)

In trying a battery element the end is not only to evaluate the exterior electro-chemical work which can be practically produced, but also to learn the variations of conditions under which this work can be effected. In order to arrive at a representation of the electro-chemical work, the graphic method appears to the Author the most advantageous. He plots down a figure which indicates the curves of electro-motive forces, current strengths, and the resistance of the battery.

The surface comprehended between this curve of current

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strengths and its two axes is proportional to the work. The ordinates of this curve represent the current strengths I, I′, I″ . . . . determined with a rheometer of small resistance, and without increasing the resistance of the exterior circuit. The ordinates of another curve represent the corresponding electro-motive forces E, E′, E″ . . . , quantities which may be determined directly by a sine or tangent galvanometer sufficiently delicate to indicate variations of current strength that may take place with an exterior electrical resistance equal to that of 310 miles of telegraph wire of 4 millimètres diameter.

By means of these two curves of current strengths and electro-motive forces, and by simple interpolation, a certain electro-chemical work being given, it will always be easy to deduce the electro-motive force and corresponding current strength of the battery which will produce this work. On the other hand, by the aid of the two curves representing current strengths and electro-motive forces, the ordinates may be calculated which will determine a very interesting third curve representing the variations of the internal resistance of the battery. These ordinates are obtained graphically by tracing a third proportional between the curve of the electro-motive forces and the corresponding curve of current strengths.

The Author also gives the following practical messurements:—A Daniell cell with porous pot 4·7 inches (12 centimètres) high, in use about three weeks—that is to say, under the best conditions for work, for the porous pot was slightly incrusted with a deposit of copper and the zinc solution half saturated with sulphate of zinc—gave a resistance of 913 yards of wire of 4 millimètres diameter at + 10°. Submitting this cell to a temperature of 0°, the resistance became equal to 1,375 yards; at −4°, 1,531 yards; and at −6°, the crystallisation being considerably greater, part of the salt was precipitated into a pasty and nearly solid mass; at − 10° the measurement of resistance was no longer possible, but had attained about 12·5 miles.

A sulphate of protoxide of mercury cell presented the same phenomena. A peroxide of manganese battery under the same conditions with an initial resistance of 251·5 yards gave at − 18° only 461·5 yards. A saturated solution of copper sulphate solidifies at − 5°; a concentrated solution of sulphate of zinc solidifies at − 7°.

These results are interesting for telegraphy in the north of Europe.

P. H.

On the Electric Conductivity of Water and other Inferior Conductors. By F. Kohlrausch.

(Annalen der Physik und Chemie Ergänzungsband, vol. viii., p. 1, and vol. clix., p. 233.)

There are few subjects upon which so many researches have been made as upon the electric conductivity of water. If 10^{10} represent

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the conductivity of mercury, the conductivity of water according to—

Pouillet	is 80	Rossetti	is 4·5
Becquerel	„ 70	Quincke	„ 2·16 (at 15°·5)
Oberbeck	„ 15	Magnus	„ 1·33 (at 20°)

In most of these estimations the method has not been free from effects of polarisation. The method adopted by the Author included the use of induced inverse currents with a Weber electrodynamometer in a Wheatstone bridge. During the measurement the water was in contact with platinum only; and this was effected by employing two platinum capsules. Into one of these capsules the water was put, and then the bottom of the other capsule placed in the water and suitably supported. The resistance of the material filling the space between the two capsules could be thus readily measured. With mercury it was 0·00000149 Siemens unit; the diameter of the lower and larger capsule was 90 millimètres, and of the upper and smaller capsule, 70 millimètres, the concentric distance between the two capsules being 1 centimètre. The Author describes the means employed to obtain pure water. The greatest resistance obtained with pure water amounted to 20,900 Siemens units at 21°·5, from which, mercury being taken as represented by 10^{10}, the conductivity is $\frac{14900}{20900}$, or 0·71 at 21°·5. This number is about half that given by Magnus, and only $\frac{1}{120}$ of Pouillet's. Compared with the best conducting electrolyte (that is, HNO_3 30 per cent.) water is 1,080,000 times a worse conductor, silver is 1,000,000,000 times a better conductor, copper about 86×10^{10} better. The Author remarks that, supposing perfectly pure water to have no conductivity, and taking the number 0·72 as representing impurity, there results the quantity of 0·5 milligramme in 1 litre of water, a quantity so small that chemistry cannot take cognisance of it. Various water distillates were made subjects of measurement with the following results, the temperature during the estimation being about 20° to 22° (68° to 71°·6 Fahr.). These numbers show that water condensed in a glass cooler has about five times the conductivity of that condensed in a platinum cooler, and that silver gives a higher number than platinum.

No.	Fluid distilled from	Condenser.	Conductivity.
1	Various	Glass	5·4 to 12·8
2	Various	Platinum	1·6 to 1·9
3	Water with some $KHSO_4$	Glass	11·1
4	Distillate No. 3	Platinum	0·94 to 1·3
5	Water with some KHO.	Silver	1·77
6	No. 5 with some $KHSO_4$	Silver	0·99
7	No. 6	Platinum	0·78
8	Water with some $KMnO_4$	Silver	0·94 to 1·14
9	Water with $KMnO_4$ and KHO.	Silver	1·03 to 1·90
10	No. 9 with some $KHSO_4$	Silver	0·93 to 1·4
11	No. 10 longer distilled	Platinum	0·71 at 22°
12	Same briskly distilled	Platinum	1·23 at 24°
13	Same redistilled long time	Platinum	0·82 at 19°

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Two samples of rainwater collected in Darmstadt on the 11th and 12th of September, 1874, gave 19·1 and 17·3 at 13°. Distilled water allowed to stand exposed to the air for one day attained a similar high conductivity. Similar measures with snow-water indicate greater purity at lower temperatures of condensation, but also that snow-water is very pure. It was found without exception that the conductivity of water increased by its merely standing in a platinum dish. The increase varied in many of the experiments between 0·05 and 0·15 hourly. Water giving a conductivity of 0·78 when fresh, gave after 4·3 hours 1·33, after 5·7 hours 1·55, after 20 hours 3·5, after 46 hours 6·0, after 78 hours 8·5, after 174 hours 14, and after 1,060 hours 30. This last number has an error due to evaporation during the 44 days of about one-third of the fluid, but notwithstanding the conductivity had increased forty-fold. The water was covered by a glass shade, tightly but not perfectly closed, the conducting wires passing out between the base plate and the shade. In vacuo the increase of conductivity is slightly less. In an atmosphere of carbonic acid water increases in conductivity more quickly than in air. The Author believes that the chemist has at disposal a means of ascertaining the purity of water by measurement of its conductivity.

According to Saïd-Effendi[1] water conducts 200 times better than alcohol, and 250 times better than ether. The Author found that purchased absolute alcohol conducted in many cases better than the pure water prepared by him. The smallest number found for alcohol was 0·3, but for ether it was 0·008. Glacial acetic acid was found to be represented by the number 0·04, and ($SnCl_4$) chloride of tin in fluid condition by a number lower than 2. By adding the smallest quantity of water to the acetic acid its conductivity rose to 600, but water added to alcohol increased its conductivity to only 5·8. As regards chlorhydric, bromohydric, and iodohydric acids, as well as of sulphuric, phosphoric, oxalic, tartaric, and acetic acids in aqueous solutions, the Author's measurements were very numerous. All acids, which can be brought into strong solution, give, for some determined mixing proportion with water, a maximum of conductivity; for nitric acid this was found to be with 29·7 per cent. HNO_3, specific gravity 1·185, the temperature being 18° C., as with the following numbers: maximum for, muriatic acid 18·3 per cent. HCl, sp. gr. 1·092; sulphuric acid 30·4 per cent. H_2SO_4, sp. gr. 1·224; phosphoric acid 46·8 per cent. H_3PO_4, sp. gr. 1·307; oxalic acid 9·4 per cent. $H_2C_2O_4$, sp. gr. 1·045; tartaric acid 22·4 per cent. $C_4H_6O_6$, sp. gr. 1·107; acetic acid 16·6 per cent. $C_2H_4O_2$, sp. gr. 1·022. The best conducting aqueous solution of sulphuric acid conducts at least eighty-six times better than saturated H_2SO_4. The conductivities of sulphuric acid obtained by the addition of water to sulphuric anhydride have at least three maxima and two minima, the

[1] *Vide* Comptes rendus de l'Académie des Sciences, vol. lxviii. (1869), p. 1565.

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latter occurring very nearly with the combinations H_2SO_4 and $H_2SO_4 + H_2O$. The dependence of conductivity upon temperature is investigated, and the following quadratic equation obtained for the curve

$$K = \psi p - \psi' p^2,$$

where ψ and ψ' are constants, $p = 0{\cdot}05$ and $0{\cdot}10$. The values of ψ and ψ' are tabulated.

P. H.

Application of Photography to Trigonometric Surveying.

(Rivista marittima, vol. ix., p. 275.)

Lieutenant Manzi, of the Italian army, has recently produced trigonometric surveys by the aid of the camera, which have obtained the approbation of the Ministry of War, and have been considered worthy of the support of the Topographical Institute.

If it be supposed that an observer be placed at the point of vision of a theodolite station, and that the rays of light converging from the distant points of view are intercepted and marked on a diaphragm, it is evident that the angular readings obtained to such points would be identical in their bearings with the objects themselves. The perspective indication thus obtained may be mathematically used by definition of the three following constants: (1) The horizontal line; (2) the distance from the optic centre to the diaphragm; (3) the position of the principal point of view. It is thus possible to construct a camera, geometrically arranged, with an object glass so ground as to minimise the area of observation, or to allow of the establishment of a differential equation of the curve of error. By such a camera, negative views of inaccessible ground can be faithfully taken, and the angles can be either plotted or calculated. By obtaining photographs of this description from properly connected points, intersections can be obtained, either graphically or by trigonometric calculation, in the same manner as by the use of a plane table or of a theodolite. The main obstacle which Lieutenant Manzi encountered arose from the fact that if the points of observation selected were so near as to be perfectly distinct, the triangles became very ill shaped. On the other hand, very distant points were with difficulty precisely determined. This was obviated by operating on small base lines (from 400 to 800 yards) and estimating the primary triangulation by a telemeter (like that of Nolan). The application of the photographic details to the points thus fixed was then simple. In the case of inaccessible mountain country the advantages thus to be obtained are obvious. It is also a matter of no small importance as regards military recognisance. The results obtained in the course of the present year are said to be highly satisfactory.

F. R. C.

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Armour-clad Turrets.

By J. KUNKA, Lieutenant, Austrian Engineers.

(Mittheilungen über Gegenstände des Artillerie- und Genie-Wesens, 1876, pp. 33, 109, 149, 235, 4 plates.)

After giving a history of the rise and progress of armour-clad turrets, the Author supplies the following details:—

COLES' CONSTRUCTION.

The "Trusty" shield had the form of a truncated cone with an exterior diameter of 12 feet at the top, 23 feet exterior diameter at the base, 8 feet height in the clear, and 40° inclination of side. The framework which carries the armour consists of 18-inch oak timber; the armour is 4½ inches thick, and bolted to the oak frames. The shield is revolved by a turning-winch, four men being required to effect one revolution in fifty-three seconds. The weight of this shield is 140 tons, and the cost £4,200.

The turret designed for the Antwerp fort No. 3 is also conical in shape, with 30° inclination of side; the exterior diameter being 23 feet 9 inches at the base, and 15 feet at the top; the extreme height above the lower roller-path 11 feet 6 inches. The cylindrical part of the turret is 4 feet 6 inches and the conical part 5 feet high. The armour is 5½ inches thick; increased at the ports to 9½ inches. The turret is mounted in a well-shaped cavity of masonry, and its weight, including two 110-pounder breechloading guns, is 140 tons; the actual cost was £4,500. It is revolved by four sets of turning-winches; each worked by two men; one quarter-revolution can be effected in seventeen seconds.

The turrets for the "Royal Sovereign" have a cylindrical shape; the exterior diameter is 23 feet 6 inches, the interior diameter 19 feet; the height in the clear is 9 feet; the thickness of the armour is 5½ inches, increased at the ports to 9½ inches; the teak backing is 7½ inches thick, and strengthened by a lattice-work of plate iron 6 inches by ¾ inch. The upright T iron frames 10 inches by 6 inches by ½ inch, are filled in by vertical balks of teak, and an inner skin of ½ inch thickness is riveted to the flanges of the T irons. The top of the cylinder is stiffened inside by an iron ring 14 inches by 2 inches. The top is formed of I iron bars 6 inches by 5 inches by ½ inch, placed at a distance of 7 inches from centre to centre. Some of the bars are removable, to admit of the gun being entered through the top. The centre pivot is a hollow cylinder 18 inches wide. The upper armoured part of the turret is 4 feet 10 inches, and the lower unarmoured part 5 feet 8 inches high. The entrance into the turret is effected by omitting some of the frames in the lower unarmoured part. The turret is supported by twenty-two rollers, and is made to revolve by hand turning-winches. Four men can effect one quarter-revolution in seventeen seconds.

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Coles' cylindrical two-storied turret consists of a revolving upper portion and a fixed lower portion; the former contains the guns and the crew for working them, and the latter the turning gear and engines. The exterior diameter of the upper portion is 24·8 feet, the interior diameter 21·1 feet, and the height in the clear 7·2 feet. The turret side is formed of armour plates 9·6 inches thick, two layers of teak of 12·8 inches entire thickness, and a double inner skin of iron plates of 1½ inch thickness. The guns are entered through the top, for which purpose some of the beams are removable. The fixed portion of the turret is also cylindrical; it has an exterior diameter of 28·5 feet, an interior diameter of 26 feet, and a height of 8·2 feet.

The turret revolves on a hollow pivot 21·6 inches wide by means of a collar. It carries two 10-inch guns, and is made to revolve by means of a turning-winch acting on a cog-wheel fixed to the platform of the upper, revolving portion. One entire revolution can be effected by nineteen men in eighty seconds, by steam power in thirty-six seconds.

Ericsson's Constructions.

Ericsson's monitor turrets have a cylindrical shape of 20 feet exterior diameter and 9 feet height. The thickness of armour is from 8 to 11 inches, built up of plates 1 inch thick, 9 feet long, 2 feet wide, weighing 640 lbs. each. The 11-inch armour has no backing; that of the 8-inch armour is of oak 12 inches thick, placed between iron bars 12 inches by 2 inches; the thickness of armour at the ports is increased to 10 inches and 13 inches respectively; the ports admit of 10° elevation and 5° depression. The top is formed of 6-inch iron beams, let into the turret side. The entrance is through the top. The turret rests on the upper deck when not used; for action it can be lifted on its centre spindle by means of a wedge. The estimated weight is 120 tons; the cost £7,000 to £8,000. The centre spindle, to which the turret is fixed, is turned by steam power.

The thickness of the "Onondaga" turret armour was increased to 12 inches, and that of the "Dictator" to 15 inches.

The armour of the turrets for the monitors built at a later period was formed by two layers of plates, each 3 inches thick, to which 8-inch iron bars were bolted on the inside. The flat ring fixed to the deck, on which the turret rests when not used, was protected by a close-fitting breastwork from splinters and fragments. This close-fitting breastwork would, however, be the cause of great friction, and perhaps entirely stop the turret from revolving in case the centre spindle should get slightly bent. The turret is turned by steam.

Möring's Shot-proof Tower.

This shot-proof tower was designed by Marcus from the ideas of Colonel Möring. The revolving turret is placed on a masonry

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tower, and carries two 16-ton guns, throwing projectiles of 160 lbs. The top of the tower is protected by a glacis of 6-inch armour plates, allowing the guns to be depressed 4°. The turret armour is formed of eight layers of 1-inch plates; the interior diameter is 22 feet, and the height in the clear 8 feet. The top cover is conical, and formed of eight layers of iron plates; it contains openings for ventilation and light. The turret rests on twenty friction rollers; the wooden floor is supported by a platform ring, fitted with cogs for the turning of the turret. Communication is effected through a circular opening in the masonry. The total weight is 260 tons, and the cost is £21,000. One entire revolution of the turret can be effected by hand power in five minutes forty seconds.

Cavalli's Turret.

This turret may be applied both to fortification and to vessels. The exterior diameter is 19·7 feet; the height from the lower roller-path to the top of the turret is 10·5 feet. The turret armour is supported by wood framework; the form is conical, with an inclination of side of 35°; the turntable is formed of four cast-iron quadrants bolted together; the guns protruding up to their trunnions from the ports.

The total weight of the turret is 46½ tons. It can be turned by four men in two minutes, and rests on twelve conical wheels.

Piron's Revolving Cupola.

Captain Piron prefers the semi-spherical shape, because it offers a minimum of surface in comparison with other forms; and admits of a stronger construction with the same material.

The largest interior diameter of the cupola is 26 feet 3 inches. The largest exterior diameter is 27 feet 10 inches, affording room for two 36-pounders. The armour consists of eight layers of iron plates ⅛ inch thick each, and is supported by a peculiar arrangement of T iron ribs. The platform is formed of I girders and box girders. Communication is established through the hollow pivot. The cupola is carried on sixteen rollers, and its weight is 295 tons. It is fitted with four turning-winches, each worked by two men.

Schumann's Turret.

The Schumann turret, built by Cammell, of Sheffield, is cylindrical, with an arched top of 60 feet radius. The height of the revolving portion above the breastwork is 4 feet; its interior diameter is 15 feet; the exterior diameter 17½ feet. The armour in front near the ports, within an arc of 140°, is 12 inches thick; at the sides, within an arc of 50°, 9 inches thick, and the remaining part at the rear 4 inches. The turret is carried on sixteen rollers by means of a circular box girder. The weight was 45 to 50 tons, and the cost £3,600.

Four men effected one entire revolution in three minutes.

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French Turrets.

The French turrets are fixed, open at the top, and fitted with a turntable inside; their interior diameter is 18 feet, and their height 7·3 feet The side is 19·68 inches thick; it consists of armour plates 6·7 inches thick, two layers of iron plating 1 inch each thick, and a wood backing 10·8 inches thick. The gun is fired over the upper edge. The hollow cast-iron centre pivot has an interior diameter of 27½ inches, and is used for communication. The turntable is made to revolve by hand or steam power.

Eads' Turret.

The Eads' turret was first applied to the river monitors "Winnebago" and "Milwaukie," built at St. Louis; it carries two Dahlgreen 11-inch guns each; the form is cylindrical, the interior diameter 20 feet; the height in the clear 14 feet; the height of the turret above the upper deck 7 feet 6 inches; the top cover is spherical. The armour is formed of eight layers of 1-inch plates. The top cover consists of two iron girders 19 feet 2 inches long, 10 inches high, and 4½ inches wide, which support eleven beams 6 inches high, 3 inches wide, placed at a distance of 20 inches. On these are placed common railway rails covered at the top with ½-inch iron plating pierced with small holes in the manner of a sieve. The guns are mounted on a platform which can be lowered for loading. The recoil is taken up by a steam break. The turret runs on two hundred and fifty-three 3-inch balls, and the entrance to it is from the lower deck. The total weight is 180 tons.

Giese's Turret.

This turret is similar to that of Schumann. The ports are strengthened by an exterior and interior lip 3 inches thick, which increases the 8-inch turret armour to 14 inches at the ports. The turret for the 72-pounder rifled Prussian gun is dome-shaped, and has an interior diameter of 24 feet. Giese prefers the dome shape for economy, facility of construction, and strength, and proposes to use plates 2 inches thick, which could be bent to the required spherical form without impairing the texture of the iron. The extreme height above the upper edge of the glacis is 8 feet 4 inches.

The turntable is formed of I irons 6 to 9 inches deep, placed at a distance of 2 feet, and covered by corrugated iron or 4-inch planks. The armour is secured to the platform by means of wrought-iron shoes. The platform rests on rollers near the outer circumference and near the centre pivot. The entrance to the turrets is through the hollow pivot. The estimated weight is 100 tons, and the cost £12,000. It is turned by hand power, and fitted with two turning-winches, each worked by two men.

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Gruson's Turret.

Gruson advocates armour of chilled cast iron. In 1868, a Gruson turret was constructed at Tegel (Prussia), and fired at experimentally in 1869. Russia also commenced the manufacture of chilled cast-iron armour at Perm in 1871, and carried out some experimental firing at a target of this material in 1873. The results of these experiments are given in a table.

Cupolas of chilled cast iron have been erected at Hamm, near Düsseldorf, at Mainz, Metz, Strassburg, and Langlütjensand. The several pieces of armour are held together by wrought-iron bars, fitting into grooves formed in their butting edges. This is the invention of Colonel Nelson, but was first carried out practically by Gruson.

Belgian Turret.

The turrets erected at the forts La Perle and Philippe, near Antwerp, carry 9-inch and 11-inch guns, and have a range of nearly 360°. The interior diameter is 25 feet 3 inches, the exterior diameter 30 feet. The armour is 12 inches thick at the ports, everywhere else 9·8 inches; the entire thickness of backing is 8·85 inches, and consists of ⊔⊔⊔ iron filled in with teak; the armour is supported by angle-iron frames 11·2 inches deep. The spaces between the angle-iron frames are also filled in with teak. The top cover is made to remove for mounting and dismounting the gun, and is supported by ⊥ girders resting on pillars.

Russian Turret.

The interior diameter of the turret built by Messrs. Laird from the plans of General O. Guern, is 22 feet 6 inches, the height above the glacis 6 feet 6 inches, the height in the clear 8 feet 4 inches. This turret has a lower chamber 6 feet high, which rests on two masonry vaults, one below the other, the upper being 7 feet 6 inches, and the lower 10 feet high. The turret armour is 9 inches thick, with a backing of ∪ irons and wood arranged horizontally and vertically; the turret rests by means of a circular ⊥ girder on the rollers. The top is formed of radial ⊤ irons, supported by the side of the turret, by a hollow central pillar, and by two stanchions.

There are added tabulated results of experimental firing by Prussian authorities at a target, giving particulars of the guns, the weights of the projectiles, the charges of powder, the number of shots fired, and the distance to the target. Similar tables compiled from Russian experiments are also given.

C. R.

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INDEX

TO THE

MINUTES OF PROCEEDINGS,

1876-77.—PART II.

A B C process for the treatment of sewage, 111 *et seq.*

Abercrombie, F., admitted student, 104.

Abernethy, J., remarks as to the sewage question, 217.—Ditto as to the impossibility of laying down arbitrary rules for the disposal of sewage, 217.—Ditto as to the evil effects of allowing the sewage of London to flow into a river of the size of the Thames, near a populous suburb like Woolwich, 218.—Ditto as to Sir J. Hawkshaw's report on the disposal of the sewage of Glasgow, 218.

Ackermann, A. W., elected associate, 104.

Adams, W., remarks as to the repairs and renewals of locomotives, 40.—Ditto as to the mileage of engine tubes, 40.—Ditto as to no advantage being taken of the wider gauge of the Great Southern and Western railway to give more bearing surface to the axle-boxes, 41.

Alexandre, M., the Mérienne dam on the Charente, 311.

Anderson, E. W., admitted student, 1.

———, H. J. C., his modifications of the boilers in the Egyptian government sugar factories, referred to, 97.

———, W., remarks as to the combustion of refuse vegetable substances, 97.—Ditto as to Mr. Head's straw-burning engine tried at the Bedford Show of the Royal Agricultural Society, 97.—Ditto as to alterations from the first design of the boilers for consuming megass in Egypt, 97.—Ditto as to the calorific power of the Egyptian megass, 99.—"Experiments and Observations on the Emission of Heat by Hot-water Pipes," 257.

Andrews, W., elected member, 251.

Ansted, D. T., remarks as to the sewage question, 212.—Ditto as to the dry earth system, and its utility as a supplement to the water-carriage systems under certain conditions, 212.—Ditto as to the pail system and disposal of the refuse at Manchester, 213.—Ditto as to seaboard and tidal outfalls, 213.—Ditto as to the application of the dry earth system to London, 215.

Archibald, C. W., transferred member, 1.

Armour-clad turrets, 370.

Armstrong, J., remarks as to the repairs and renewals of locomotives, 41.—Ditto as to the higher expenditure per train mile for wages on the Great Western than on other railways, 41.—Ditto as to the favourable gradients on the Great Southern and Western railway of Ireland affecting the cost of working, 42.—Ditto as to the earnings of goods trains on different lines, 43.—Ditto as to the gradients on the

Digitized by Google

Great Western railway, 43.—Ditto as to the conversion of the gauge on the Great Western railway, 44.—Ditto as to the wagons and carriages, 45.—Ditto as to the design and cost of the Great Western and the Great Southern and Western goods engines, 45.—Ditto as to the fairest estimate of cost of repairs and renewals being derived from the total expenditure of the locomotive department, 46.—Ditto as to the effect of competition by shorter routes on the Great Western mileage receipts, 46.—Ditto as to the number of locomotives renewed by the Great Western Company out of revenue, 47.—Ditto as to the life of tubes, 47.—Ditto as to steel crank axles, 48.—Ditto as to an early locomotive designed to work expansively, 48.—Ditto as to a report of Mr. E. Woods on the consumption of fuel on the Liverpool and Manchester railway, 48.—TABLES: I. Distances by Great Western railway, compared with competitive routes, 49.—II. Cost of locomotive engines and tenders built by the Great Western Railway Company, 50.—III. Train miles and locomotive expenses, Great Southern and Western railway compared with other railways, 52.—III. Mileage, locomotive expenditure, traffic receipts, &c., on the Great Western railway, 53.—V. Renewal of locomotive stock, Great Western railway, 55.—VI. Average mileage of iron tubes in locomotives, Great Western railway, 54.—VII. Average age of engines, Great Western railway, 55.—VIII. Mileage of steel crank axles, Great Western railway, 56.—IX. Mileage of iron crank axles, Great Western railway, 57.—X. Mileage, locomotive expenditure, traffic receipts, &c., of the Great Southern and Western, compared with the Midland Great Western of Ireland railways, 58.

Auld, W. M., admitted student, 251.

Austin, C. E., remarks as to the sewage question, 176.—Ditto as to the system of turning the sewage into the sea being a makeshift, 177.—Ditto as to the separation of the solids, and their disposal by trenching, 178.—Ditto as to land plants not being generally adapted for the absorption of liquid sewage, 178.—Ditto as to water plants being the natural absorbents of the organic matter of sulliage, 179.—Ditto as to the water in the Thames being generally purest at the end of the warm weather in autumn, before the weeds begin to decay, 179.

———, G., admitted student, 104.

Bagass, combustion of, under steam boilers, 96.

Bain, T. C. J., elected associate, 104.

Baldry, H. O., elected associate, 104.

Barclay, H. V., elected associate, 1.

Barré, M., disengagement of ammonia in rupture of steel, 356.

Bazalgette, C. N., "The Sewage Question," 105.—Remarks as to ditto, 160.—Ditto as to the comparative values of water and sewage as irrigants, 160.—Ditto as to the progress of sewage utilisation processes, and the antiquity of the best form of sewage irrigation practised in the present day, 237.—Ditto as to the mischievous effect of waiting for further discovery, 238.—Ditto as to the A B C process, 238.—Ditto as to the value of water as an irrigant, 239.—Ditto as to Dr. Frankland's experiments on the defecating power of soils, 240.—Ditto as to his contested statements with regard to intermittent downward filtration, as practised at Merthyr Tydvil and Kendal, 240.—Ditto as to the dry earth system at Manchester, 248.—Ditto as to tidal outfalls, 249.—Ditto as to a tidal outfall for the Thames valley drainage, 249.—Ditto as to the effect of the metropolitan sewage outfall on the town of Barking, 250.

————, Sir J. W., remarks as to the sewage question, and to the alleged

Digitized by Google

silting-up of the bed of the Thames by deposit from the metropolitan sewage outfalls, 225.—Ditto as to intermittent downward filtration, 231.—Ditto as to the A B C process at Crossness, 233.—Ditto as to the Liernur system, 234.
Beresford, J. S., memorandum on the irrigation duty of water, and the principles on which its increase depends, 319.
Beynon, G. W., elected associate, 251.
Bilia, S., works undertaken for the consolidation of the bed of the Calabrian railway, 277.
Bird's process for the treatment of sewage, referred to, 118.
Black, —., his experiment as to the calorific power of megass at the Magaga sugar factory, Egypt, referred to, 99.
Blackbourn, H., elected associate, 1.
Blackburn, H. R., admitted student, 1.
Blanc, F. Le, mechanical separation of matters in suspension in gas or vapours, 331.
Blasting of ice, on the, 310.
Blyth, B. H., elected member, 104.
Bodson, M., the Gileppe dam, 312.
Bond, C. P. W., admitted student, 104.
Botley, C. E., elected associate, 104.
Boys, W. J., elected associate, 104.
Bramwell, F. J., remarks as to the combustion of refuse vegetable substances, 92. —Ditto as to experiments with megass at Cairo, in March 1874, 92.—Ditto as to the unfavourable results obtained by stoking megass by manual labour, 92. —Ditto as to the importance of the issues involved in the introduction of cheap fuel into corn-growing countries, 93.
Bridge over the Nieuwe Maas, Rotterdam, accident to a caisson at the Willems, 299.
Bridgford, Capt. S. T., elected associate, 104.
Brunel, H. M., elected member, 251.
Brushwood, combustion of, under steam boilers, 75.
Bullmore, F. C., transferred member, 251.
Burnett, A. W., elected member, 251.
———, R. R., elected member, 104.
Bury, T. T., memoir of, 269.

Cailletet, L., manometer for high pressures, 340.
Caldicott, H., admitted student, 104.
Campbell, D., his process for the treatment of sewage, referred to, 118, 119.
Canadian narrow-gauge railways. *Vide* Railways.
Canal, river Rhone irrigation, 315.
Carroll, E. B., transferred member, 104.
Chemical treatment of sewage, 106 *et seq.*
Clarifying and Utilisation of Sewage Company, process of the, for the treatment of sewage, referred to, 118.
Cobley, W. H., elected associate, 1.
Cole, W. R., elected member, 104.
Collins, H. R., elected associate, 251.
Combustion of refuse vegetable substances under steam boilers, 75.
Condensation and re-evaporation of steam in the cylinders of steam engines, 336.

Digitized by Google

Consolidation of the bed of the Calabrian railway, near Torre Vecchia, works undertaken for the, 277.
Copper sheathing, action of sea-water upon, 74.
Cotton, J. L., admitted student, 1.
Cotton stalks, combustion of, under steam boilers, 75.
Cottrell, H. E. P., elected associate, 104.
Cowper, E. A., remarks as to the combustion of refuse vegetable substances, 100. —Ditto as to modifications of the ordinary fire-box necessary when burning sawdust, shavings, and other fine refuse, 100.—Ditto as to the results of stoking at the Royal Agricultural Society's trials, 101.
Cracroft, E. H. B., admitted student, 104.
Crawford, J. B., elected associate, 104.
Creighton, J. G. A., elected associate, 1.
Crompton, E., admitted student, 251.
Crookes, W., remarks as to the sewage question, 163.—Ditto as to its solution demanding the intelligent co-operation of several professions, 163.—Ditto as to irrigation, 164.—Ditto as to intermittent downward filtration, 165.—Ditto as to the "waste" system, 165.—Ditto as to phosphate processes, 166.—Ditto as to the A B C process, and the manurial value of native guano, 167.—Ditto as to the cost of the purification effected by the A B C process, 170.—Ditto as to the ultimate results of the continued waste of sewage, 173.
Cundall, J. H., elected associate, 251.
Cunningham, A., Capt. R.E., hydraulic experiments at Roorkee, 1875-76, 322.

Dalmann, H., regulation of the North Elbe, 307.
Dam on the Charente, the Mérienne, 311.
——, the Gileppe, 312.
Darwin, H., elected associate, 104.
Davey, H., elected associate, 104.
Dean, W., elected associate, 251.
Dees, J. G., elected associate, 104.
Denton, J. B., his arrangement for the treatment of sewage by intermittent downward filtration, referred to, 131 *et seq.*—Remarks as to the sewage question, 181. —Ditto as to the opinions erroneously attributed to him by Mr. Bazalgette, 182.—Ditto as to intermittent downward filtration, 182.—Ditto as to the filtration works at Merthyr, 183.—Ditto as to how the different modes of treating sewage affected the ratepayers, 184.—Ditto as to intermittent downward filtration at Kendal, 185.—Ditto as to the opinion of the late Dr. von Liebig in favour of intermittent filtration through natural soil, 187.—Ditto as to the silting-up of tidal channels from the outflow of sewage, 187.
Detienne, E., the Gileppe dam, 312.
Dick, G. G., elected associate, 104.
Downing, S. F., elected associate, 251.
Dunlop, H. G., elected associate, 104.
Dunsdon, W. T., admitted student, 1.
Dynamite, temperature of explosion of, 363.
————, volatility of nitroglycerine in, 364.

Eagles, T. H., elected associate, 1.
Edwards, O. C., memoir of, 266.
Electric conductivity of water and other inferior conductors, on the, 366.

Digitized by Google

Escher, R., Prof., on the theory of the centrifugal pump, 345.
Excavating apparatus, Gatmell's, for removing clay from deep foundation cylinders under water, 103.
"Experiments and Observations on the Emission of Heat by Hot-water Pipes," 257.

Fairbank, F. G., admitted student, 105.
Farquhar, F. U., Col. U.S.E., on blasting of ice, 311.
Fenwick, G. T., elected associate, 104.
Field, R., remarks as to the sewage question, 205.—Ditto as to intermittent downward filtration at Merthyr Tydvil, 205.—Ditto, ditto at Kendal, 206.—Ditto as to the method of distributing sewage by notch plates, 207.—Ditto as to the difference between irrigation and intermittent downward filtration, 209.
Filtration, intermittent downward, for sewage, 105. *Vide* "The Sewage Question."
Fitz-Gerald, W. G., elected associate, 104.
Flagg, J. F., efficiency of steam vacuum pumps, 340.
Flames, on the influence of pressure on, 329.
Forbes, D., and Price, A. P., their phosphate of alumina process for the treatment of sewage, referred to, 115.
Foxlee, W. T., elected associate, 1.
Frankland, Dr. E., his system for the treatment of sewage by intermittent downward filtration, referred to, 126 *et seq.*—Remarks as to the sewage question, 188.—Ditto as to the chemical aspect of the question, 188.—Ditto as to the comparative value of pure water and of sewage for irrigation, 191.—Ditto as to the quantity of sewage necessary to fertilise an acre of land, 191.—Ditto as to intermittent downward filtration and laboratory experiments thereon, 192.—Ditto as to the practical results obtained at Merthyr Tydvil, 194.—Ditto as to the scheme proposed by Mr. Hawksley and Mr. Hope for dealing with the sewage of Birmingham, 197.—Ditto as to the disposal of the sewage of seaboard towns, 198.
Fraser, C., admitted student, 105.
Fuel, combustion of, under steam boilers, 75.
——, on the production of compressed, from earthy lignite in Prussia, 349.

Gabbett, E. R., elected associate, 104.
Gallwey, W. H. P., admitted student, 105.
Galvanic batteries, practical method for trial of, 365.
Garrett, F., remarks as to the combustion of refuse vegetable substances, 93.—Ditto as to straw-burning engines of Messrs. Garrett and Kotzo, 93.—Ditto as to the construction of a boiler for the consumption of straw, 93.—Ditto as to automatic stoking, the mechanical pricker for fire-bars and the pipe for conveying water to the ash-pit, 94.—Ditto as to the grate area and heating surface, 94.—Ditto as to the relative weights of straw-burning engines, 94.—Ditto as to skilled engine-drivers for stoking straw, 95.—Ditto as to experiments with Kotzo's engine in May and June 1875, 95.—Ditto as to Mr. Head's formula for evaporation, 95.—Ditto as to the arrangement of the fire-bars in Kotzo's engine, 96.—Ditto as to the difficulties in the way of introducing straw-burning engines in England, 96.
Gas, lighting of trains by, in the Mont Cenis tunnel, 328.
—— or vapours, mechanical separation of matters in suspension in, 331.
Gasholder of the Berlin Gas Works, 326.

Digitized by Google

Gas works, gasholder of the Berlin, 326.
————, the Brussels, 324.
Gatmell, R., his apparatus for excavating clay in deep foundation cylinders under water, 103.
Gerrard, A. S., elected associate, 1.
Gill, C., admitted student, 1.
——, J. M., admitted student, 251.
Glass, on the recovery of sulphur from gypsum and sulphate of soda in the manufacture of, 362.
Gooch, H., transferred member, 104.
Goodall's process for the treatment of sewage, referred to, 118.
Green, C. F., elected member, 1.
——, R. W. E., memoir of, 270.
Gypsum, on the recovery of sulphur from, in the manufacture of glass, 362.

Hamilton, E., elected student, 1.
Hammers, atmospheric, 346.
Harbour improvement, principles of tidal, as applied at Wilmington, Cal., 293.
Hardwicke, A., elected associate, 104.
Harman, H. J., elected associate, 104.
Harpur, S., analysis of his evidence, before the Rivers Pollution Commissioners, in favour of the treatment of the sewage of Merthyr Tydvil by intermittent downward filtration, 133 *et seq.*
Hart, J., elected associate, 104.
Hautefeuille, P., calorimetric researches on the carbides and silicides of iron and manganese, 356.
Hawkshaw, Sir J., remarks as to the maintenance and renewals of locomotives, 60.—Ditto as to the term "train mileage" having a different meaning on different railways, 60.—Ditto as to iron tubes for locomotives, 68.—Ditto as to the disuse of brass or copper tubes in the United States, 68.—Ditto as to the probable advantages of steel fire-boxes and iron tubes, 68.
Head, J., remarks as to the repairs and renewals of locomotives, 68.—"On the Combustion of Refuse Vegetable Substances, such as Straw, Reeds, Cotton Stalks, Brushwood, Megass, &c., under Steam Boilers," 75.—Remarks as to ditto, 92.—Ditto as to the general principles of his engine, 101.—Ditto as to the desirability of obtaining more definite information of the conditions under which steam power was used in the colonies, 101.—Transferred member, 251.
Heat, "Experiments and Observations on the Emission of Heat by Hot-water Pipes," 257—Formula in general use for expressing the process of cooling by radiation, 257.—Apparatus used in the experiments, 257.—Explanation of the diagram, 258.—Results with pipes of different diameters, 259.—Values of the co-efficient of radiation derived from experiments, 260.—Difference in the rate of cooling between the 2-inch and 4-inch pipes, 261.—Conclusions deduced from the experiments, 262.—Examples of buildings and rooms warmed by hot-water pipes, 265.
——, latent, simple relations between the, atomic weight and tension of vapours, 332.
——, application of the mechanical theory of, to the study of volatile liquids, 332.
Heinke, F. W., elected associate, 104.
Henderson, W. S., elected associate, 1.
Hepworth, J., elected associate, 251.

Digitized by Google

Hess, B., on an underground pumping engine at Fohnsdorf, 341.
——, P., temperature of explosion of dynamite, 363.—Volatility of nitroglycerine in dynamite, 364.
Hethrington, F. J., admitted student, 1.
Holme, A. H., elected associate, 251.
Hope, W., remarks as to the sewage question, 179.—Ditto as to the Birmingham sewage scheme, 180.—Ditto as to the alleged escape of nitrogen in the effluent water from irrigation, 180.—Ditto as to the value of sewage as a manure, 180.—Ditto as to there being nothing unwholesome in the produce from sewage irrigation, 181.—Ditto as to the present metropolitan sewage outfalls not having been designed for the permanent disposal of the sewage of London, 181.
Houghton, T. H., admitted student, 105.
Hughes, H., remarks as to the repairs and renewals of locomotives, 59.
Hunt, E. J., elected associate, 1.
Hydraulic experiments at Roorkee, 1875–76, 322.

Ice, on the blasting of, 310.
Illeck, J., hypothesis on the condensation and re-evaporation of steam in the cylinders of steam engines, 336.
Intermittent downward filtration, 105. *Vide* "The Sewage Question."
Iron, calorimetric researches on the carbides and silicides of, and manganese, 356.
——, on the manufacture of white forge pig, from the oolitic iron ores of Luxemburg, 352.
Irrigation canal, Rhone, 315.
——— duty of water, and the principles on which its increase depends, 319.
———, sewage, 105. *Vide* "The Sewage Question."

Jeffreys, E. H., admitted student, 251.
Joel, H. F., elected associate, 104.
Jones, Lieut.-Col. A. G., remarks as to the sewage question, 174.—Ditto in refutation of the statement that little progress had been made in the chemical treatment of sewage during the last twenty-five years, 174.—Ditto as to the Wrexham irrigation farm, 174.—Ditto as to intermittent downward filtration at Merthyr and at Doncaster, 175.—Ditto as to the cost of drying the sludge from precipitation processes, 176.—Ditto as to the profits from sewage farms, 221.
——, C. W., elected associate, 251.
——, W. J., elected associate, 104.
Julien, P., the Brussels Gas Works, 324.

Kendal, intermittent downward filtration for the treatment of sewage at, 140 *et seq.*
Kirtley, W., remarks as to the repairs and renewals of locomotives, 61.—Ditto as to the difficulty of getting out statistics in the case of the larger railway companies, 61.—Ditto as to the cost of materials for the repairs and renewals of railway rolling stock, 62.—Ditto as to the new lines of the Midland Company probably influencing the ratio of renewals to new stock, 62.—Ditto as to the life of the various parts of the locomotives on the Midland, and the London, Chatham, and Dover railways, 63.—Ditto as to crucible cast steel crank axles on the London, Chatham, and Dover railway, 65.—Statistics of the

Digitized by Google

locomotive, carriage, and wagon departments of the leading railways in the United Kingdom, 66–67.
Kohlrausch, F., on the electric conductivity of water and other inferior conductors, 366.
Koning, D. A. W., accident to a caisson at the Willems bridge, over the river Nieuwe Maas, Rotterdam, 299.
Kotzo, —., his patent for straw-burning engines, 93 *et seq.*
Kunka, J., armour-clad turrets, 370.

Lane, C. B., memoir of, 266.
Law, H., remarks as to the sewage question, 201.—Ditto as to the disposition of the land under treatment by filtration at Merthyr Tydvil, 201.—Ditto as to the profit at Merthyr, 202.—Ditto as to the effect of subsoil water on the purity of the effluent, 202.—Ditto as to the different conditions of laboratory experiment and practical application, 204.—Ditto as to the disposal of sewage sludge, 204.
Leclanché, L., practical method for trial of batteries, 365.
Leclercq, F., the Gileppe dam, 312.
Lederer, I., regulation of the Danube at Vienna. Removal of the old river works at Nussdorf, 304.
Lemon, J., transferred member, 104.—Remarks as to the sewage question, 235.—Ditto as to the Dutch report on the Liernur system, 235.—Ditto as to the assertion that no chemical process could deal single-handed with sewage, 235.—Ditto as to the Birmingham Sewage Bill, 235.—Ditto as to the proper data for sewage irrigation, 235.—Ditto as to subsoil water, 235.—Ditto as to seaboard and tidal outfalls, 236.—Ditto as to a means of obviating the alleged deposit in the Thames, 236.
Liebig, Dr. J. von, letter of, to Mr. J. B. Denton on the disposal of sewage by intermittent downward filtration, 187.
Liernur, Capt., his system for the treatment of sewage, referred to, 147 *et seq.*
Lignite, on the production of compressed fuel from earthy, in Prussia, 349.
Lime process, the, for the treatment of sewage, 108 *et seq.*
Liquids, application of the mechanical theory of heat to the study of volatile, 332.
Littler, R. D. M., remarks as to the sewage question, 219.—Ditto as to the causes of the non-success of sewage farms, 219.—Ditto as to the Crossness outfall of the metropolitan drainage works in relation to the alleged silting-up of the bed of the Thames, 220.
Lockhart, W. S., elected associate, 1.
Locomotives, "The Repairs and Renewals of Locomotives," 2.—Conditions which govern the expenditure in maintaining locomotives, 2.—Cost of repairs and renewals of locomotives on six of the principal railways from July 1868 to December 1875, 2.—Class of stock on the Great Southern and Western railway, 4.—Express engine, 4.—Light passenger engine, 6.—Six-wheel coupled goods-engine, 6.—Cost of wages and materials in pence per train mile, from January 1866 to December 1875, 9.—Mileage of steel tires, 11.—Mileage of iron crank axles, 11.—Mileage of Bessemer steel crank axles, 12.—Material of the boiler tubes, 13.—Average rate of wages per day, 14.—APPENDICES: Tables of repairs and renewals per train mile: I. English railways, 16.—II. American railroads, 18.—III. French railways, 19.—IV. Prussian railways, 26.—V. Great Southern and Western railway of Ireland, 27.

Digitized by Google

Longridge, J. A., remarks as to the consumption of bagass (megass) as fuel in Mauritius, 96.—Ditto as to the form of furnace and method of stoking, 97.

Macalister, D., admitted student, 1.
McDonnell, A., "The Repairs and Renewals of Locomotives," 2.—Remarks as to the first cost of the engines on the Great Southern and Western railway of Ireland, 35.—Ditto as to steel fire-boxes and iron tubes, 68.—Ditto as to there being no more distinct unit for comparison than train mileage, 69.—Ditto as to the relative increase in the engines of the Great Northern and the Great Western companies, 69.—Ditto as to repairs per engine and per train mile, 70.—Ditto as to the mileage of tubes, 70.—Ditto as to the size of the journals in crank axles, 70.—Ditto as to the high proportion of Great Western repairs, 71.—Ditto as to whether cheap engines were the most economical in the long run, 71.—Ditto as the most economical materials for the construction and repair of locomotives, 72.
Machinery for crushing sugar-cane, and expressing the juice, 348.
Mackie, C. H., elected associate, 251.
Mackintosh, P. A., elected associate, 251.
McLellan, G., elected associate, 104.
Manganese, calorimetric researches on the carbides and silicides of iron and, 356.
Manometer for high pressures, 340.
Marshall, W. B., elected associate, 104.
Martin, T. H., elected associate, 251.
Mason, T., elected associate, 104.
Matthews, T., elected associate, 104.
————, W. M., elected associate, 251.
Mayne, E., admitted student, 105.
Megass, consumption of, under steam boilers, 75. *Vide* Refuse vegetable substances.
Mercury, on the influence of temperature on the specific heat of, 357.
Merthyr Tydvil, intermittent downward filtration for the treatment of sewage at, 127 *et seq.*
Michel, J., sorting sidings for marshalling goods trains, 285.
Mignon and Rouart, machinery for crushing sugar-cane, and expressing the juice, 348.
Morton, C., remarks as to the sewage question, 209.—Ditto as to the effluent from the filter beds at Merthyr Tydvil, 209.—Ditto as to the extra duty imposed upon the soil directly surrounding the carriers, 210.—Ditto as to the question of profit from sewage farming, 210.—Ditto as to dismantling the filter beds at Merthyr, 210.—Ditto as to the cost of preparing land for sewage farming, 212.—Ditto as to the theory of intermittent downward filtration, 212.
Moule, Rev. H., dry earth system of, referred to, 143 *et seq.*
Moyle, S., elected associate, 251.
Mulock, G. P., elected associate, 1.

Nice, A. S., elected associate, 104.
Nitroglycerine, volatility of, in dynamite, 364.
Nyströmer, C. A. B., elected associate, 104.

Ogilvie, A. G., elected associate, 251.

Digitized by Google

Pacho, G., on the construction and working of the St. Gothard railway, 274.
Pain, C. S., elected associate, 1.
Park, J. C., elected member, 104.
Peile, Col. F. W., remarks as to Gatmell's apparatus for excavating clay in deep foundation cylinders under water, 103.
Percy, Dr., remarks as to the action of sea-water on a piece of copper sheathing from H.M.S. "Argonaut," 74.
Perram, H. C., elected associate, 251.
Pettigrew, W. F., admitted student, 105.
Phosphate of alumina process for the treatment of sewage, referred to, 115 *et seq.*
——— Sewage Company's process for the treatment of sewage, referred to, 115 *et seq.*
Photography to trigonometic surveying, application of, 369.
Pictet, R., application of the mechanical theory of heat to the study of volatile liquids, simple relations between the latent heat, atomic weight and tension of vapours, 332.
Pitt, R. F., admitted student, 1.
Portugal, H.M. Dom Luis, King of, elected honorary member, 104.
Price, A. P., and Forbes, D., their phosphate of alumina process for the treatment of sewage, referred to, 115 *et seq.*
———, J., jun., admitted student, 105.
———, P. L. A., admitted student, 105.
Prichard, E. E., elected associate, 251.
Pump, on the theory of the centrifugal, 345.
Pumping engine at Fohnsdorf, on an underground, 341.
Pumps, efficiency of steam vacuum, 340.

Rail production in Russia, measures for the development of, 291.
Rails, on the length of Bessemer steel, 288.
Railway carriage traverser worked by endless rope, 292.
———, Great Southern and Western of Ireland, cost of maintenance and renewals of locomotives on the, 2 *et seq.*
———, Great Western, statistics of locomotive department of the, 41 *et seq.*
———, Liverpool and Manchester, early efforts to reduce the consumption of coke upon the, 48.
———, Midland of Canada, 254.
———, Mont Cenis, lighting of trains by gas in the Mont Cenis tunnel, 328.
———, Northern of Canada, 254.
———, on the construction and working of the St. Gothard, 274.
———, Toronto and Nipissing, 252.
———, Toronto, Grey, and Bruce, 252.
——— rolling stock. *Vide* Locomotives.
——— works undertaken for the consolidation of the bed of the Calabrian, near Torre Vecchia, 277.
Railways, "Canadian Narrow-gauge Railways," 252.—Causes which have led to the adoption of a narrow gauge for branch lines in Canada, 252.—Toronto, Grey, and Bruce railway, 252.—Toronto and Nipissing railway, 252.—Permanent way and rolling stock in use on the foregoing lines, 253.—Recent adoption of heavier rails for narrow-gauge lines necessitated by the increased traffic, 254.—Comparison of the narrow-gauge lines with the Northern and the Midland railways of Canada, 254.—Tabulated statement of receipts and expenditure on

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railways of 3 feet 6 inches gauge, compared with railways of 5 feet 6 inches and 4 feet 8½ inches gauge, 255.
Railways, Italian, in 1875, 282.
————, Prussian, in 1875, 280.
————, sorting sidings for marshalling goods trains, 285.
Randolph, G. W., elected associate, 104.
Ransome, R. C., remarks as to the consumption of megass as fuel for steam engines in Egypt, 102.
Raynes, T., admitted student, 1.
Read, R. H., admitted student, 105.
Reeds, combustion of, under steam boilers, 75. *Vide* Refuse vegetable substances.
Refuse vegetable substances. "On the Combustion of Refuse Vegetable Substances, such as Straw, Reeds, Cotton Stalks, Brushwood, Megass, &c., under Steam Boilers," 75.—Conditions which govern the advantageous use of other fuel than coal or wood as fuel for generating steam, 75.—Increase in the price of wood fuel in Central Europe, 76.—Experiments of Messrs. Head and Schemioth in 1872, 77.—Table showing the chemical composition of various substances now used for fuel, 78.—Earliest adaptation of a brick furnace to burning straw, 79.—Method employed in Hungary and Wallachia for burning straw, 79.—Method of continuously feeding the vegetable refuse by mechanical means, 80.—10-HP. engine made by Ransomes, Sims and Head, on Head and Schemioth's patent, 81.—Relative area of grate surface necessary for burning coal and vegetable refuse, 81.—Self-feeding apparatus applied to the experimental engine, 81.—Arrangements for preventing the deposit of silica on the fire-bars, 82.—Mode of dealing with the light ashes so as to prevent danger from sparks, 83.—Adaptation of the engine to ordinary fuels, 83.—Experiments at the Orwell Works in 1875, 84.—Dimensions and weights of portable engines fitted with Head and Schemioth's apparatus, 85.—Applicability of the system to Egypt for burning cotton stalks and megass, 86.—Steam cultivation of the land, 87.—Adoption of Head and Schemioth's system by Messrs. Fowler and Co. for steam ploughing engines, 88.—Modifications introduced by Mr. D. Greig, 89.—Practical application to steam cultivation in Russia, 89.—Various inventions recently introduced for burning straw, 90.—Probable increased difficulty in obtaining fuel as the demand for mechanical appliances extends, 91.
Regulation of the Danube at Vienna, 304.
Reid, J., elected member, 104.
Reservoirs of the Rio Rimac, Peru, 318.
Richter, H., on the reduction of silver ores by the Californian method in Mexico, 358.
River Aar, improvement of the, between Thun and Uttigen, 302.
—— Charente, the Mérienne dam on the, 311.
—— Danube at Vienna, regulation of the, removal of old river works at Nussdorf, 304.
—— Nieuwe Maas, Rotterdam, accident to a caisson at the Willems bridge over the, 299.
—— North Elbe, regulation of, 307.
—— Rhone irrigation canal, 315.
—— Rimac, Peru, reservoirs of the, 318.
Rivers Danube and Regen, on the laying of subaqeous mains of the Regensburg Waterworks across the, 322.

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Rivers Pollution Commissioners, the, and intermittent downward filtration for the treatment of sewage, 126 *et seq.*
Robinson, H. C., admitted student, 1.
Rogers, W., elected associate, 104.
Rolling stock, railway. *Vide* Locomotives, and Railways.
Rothwell, R. M., elected associate, 251.
Ryan, T. T., memoir of, 272.

St. George, P. W., elected associate, 104.
Sawdust as fuel for steam engines, mode of using, 100.
Schemioth, —., his boiler for the combustion of refuse vegetable matter as fuel, 75 *et seq.*
Schott, O., Dr., on the recovery of sulphur from gypsum and sulphate of soda in the manufacture of glass, 362.
Schultz, R. A., on the production of compressed fuel from earthy lignite in Prussia, 349.
Schwedler, W., gasholder of the Berlin Gas Works, 326.
Scott, A., remarks as to the sewage question, 215.—Ditto as to the statements of Mr. Bazalgette with respect to the Lieurnur system, 215.—Ditto as to the application of that system at Dordrecht and Leyden, 216.
——, C. S., admitted student, 251.
——, Gen. H. Y. D., remarks as to the sewage question, 160.—Ditto as to the sufficiency of precipitation processes for the purification of sewage, 160.—Ditto as to the cement process at Birmingham, 161.—Ditto as to the best means of disposing of the sludge resulting from the lime process, 163.
——, W., elected associate, 1.
Seaboard and tidal outfalls for the reception of sewage, 156 *et seq.*
Sea-water, action of, on copper sheathing, 74.
Sears, C. B., principles of tidal harbour improvement, as applied at Wilmington, Cal., 293.
Sewage, "The Sewage Question," 105.—Little practical progress made during the last twenty-five years towards a solution of the sewage difficulty, 105.—I. Treatment with chemicals, 106.—Scott's process, 107.—The lime process, 108.—The A B C or Sillar's process, 111.—The sulphate of alumina and milk of lime process of the General Sewage Manure Company, 115.—The phosphate of alumina (Forbes and Price) process of the Phosphate Sewage Company, 115.—Goodall's process, 118.—Bird's process, 118.—D. Campbell's process, 118.—Whitthread's process, 119.—Conclusions deduced from a consideration of the foregoing chemical process, 121.—II. Application of sewage to land, 122.—Irrigation, 123.—Intermittent downward filtration, 125.—Conclusions in respect of irrigation and intermittent downward filtration, 143.—III. The dry earth system, 143.—Estimate of the cost of introducing Moule's earth closet system into London, 145.—IV. The Liernur or pneumatic system, 147.—Application at Leyden, 149.—At Amsterdam, 153.—At Dordrecht, 155.—V. Seaboard and tidal outfalls, 156.—Apprehension as to the silting-up of tidal outfalls from the admission of sewage, 157.—Recapitulation of conclusions, 158.
Shavings, as fuel for steam engines, 100.
Shelford, W., remarks as to the sewage question, 221.—Ditto as to the difficulty of treating sewage sludge by precipitation processes, 222.—Ditto as to seaboard and tidal outfalls, 222.—Ditto as to the silting-up of the bed of the Thames by deposit from the metropolitan sewage outfalls, 222.—Ditto as to the recommen-

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dations of Col. Cox in respect of the Thames valley drainage, 223.—Ditto as to the sections of the Thames exhibited by him, 234.
Ship-repairing slip at Palermo, 297.
Shoolbred, J. N., remarks as to the sewage question, 224.—Ditto as to the deposit of mud in the Mersey from the sewage of Liverpool, 224.—Ditto as to the tidal outfall not being a simple solution of the question, as contended by Mr. Bazalgette, 225.
Siemens, Dr. C. W., remarks as to the combustion of refuse vegetable substances, 99.—Ditto as to the straw-burning engines of Messrs. Ransomes, Sims and Head, and Messrs. Garrett at the Vienna Exhibition, and their relative efficiency, 99. —Ditto as to a suggested solution of the apparent discrepancies in the calculations of Mr. Head and Mr. F. Garrett, 100.
Sillar, W. C., his A B C process for the treatment of sewage, 111 *et seq.*
———, remarks as to the sewage question, 198.—Ditto as to the action of the blood in the A B C process, 198.—Ditto as to occasions when irrigation or filtration is inapplicable, 198.—Ditto as to the power of the A B C process to purify the effluent, 199.—Ditto as to the manurial value of native guano, 199.
Silver ores, on the reduction of, by the Californian method in Mexico, 358.
Small, J. M., elected associate, 251.
Smith, C. G., elected associate, 251.
———, E. B., elected associate, 104.
———, E. M., admitted student, 251.
———, W. A., elected associate, 1.
Smythe, A. J. H., elected associate, 1.
Solly, H. le G., admitted student, 1.
Stawell, J. M., admitted student, 105.
Steam in the cylinders of steam engines, condensation and re-evaporation of, 336.
——— vacuum pumps, efficiency of, 340.
Steel, disengagement of ammonia in rupture of, 356.
—— rails, on the length of Bessemer, 288.
Stephenson, G. R., President, remarks as to the repairs and renewals of locomotives, 72.—Ditto as to the increase of traffic on the principal lines of late years having prevented the companies from properly maintaining their engines, 72.—Ditto as to the disadvantages of the high speeds at present maintained, 73.—Ditto as to how interest on capital was charged by the companies, 73.—Ditto as to the high charge for renewals on the North Eastern railway, 73.—Ditto as to the combustion of refuse vegetable substances under steam boilers, 102.
Stirling, P., remarks as to the repairs and renewals of locomotives, 59.—Ditto as to the life of engine boilers, 59; the cost of repairs and renewals, and the life of crucible-cast and Bessemer steel crank axles and tires on the Great Northern railway, 59.
Straw, combustion of, under steam boilers, 75. *Vide* Refuse vegetable substances.
Stroudley, W., transferred member, 104.
Stürmer, Prof. Dr., Italian railways in 1875, 282.
Sugar-cane, machinery for crushing, and expressing the juice, 348.
Sulphate of alumina and milk of lime process for the treatment of sewage, 115.
——————— soda, on the recovery of sulphur from gypsum and, in the manufacture of glass, 362.
Sulphur, on the recovery of, from gypsum and sulphate of soda, in the manufacture of glass, 362.
Summers, T., admitted student, 1.

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Sumner, H. G., admitted student, 1.
Surveying, application of photography to trigonometric, 369
Swindlehurst, R. H., elected associate, 104.

Tait, G. H., transferred member, 1.
Tayler, H. G., admitted student, 251.
Temperature, on the influence of, on the specific heat of mercury, 357.
Theis, W., repairing slip at Palermo, 297.
Thieme, A., on the laying of subaqueous mains of the Regensburg Waterworks across the Danube and the Regen, 322.
Tidal harbour improvement, principles of, as applied at Wilmington, Cal., 293.
Traverser worked by endless rope, carriage, 292.
Troost, L., calorimetric researches on the carbides and silicides of iron and manganese, 356.
Tulloch, F. H., admitted student, 1.
Turner, W. B., transferred member, 1.
Turrets, armour-clad, 370.
Uhagon, R. de, elected associate, 104.

Unwin, H., transferred member, 1.
Utilisation of sewage. *Vide* "The Sewage Question."

Valentine, F., elected associate, 251.
Vapours, mechanical separation of matters in suspension in gas or, 331.
———, simple relations between the latent heat, atomic weight and tension of 332.
Vidalin, T., the Rhone irrigation canal, 315.
Voysey, H. W., admitted student, 105,

Wallace, J., jun., admitted student, 1.
Warming, "Experiments and Observations on the Emission of Heat by Hot-Water Pipes," 257.
Wartha, V., Prof., on the influence of pressure on flames, 329.
Water, on the electric conductivity of, and other inferior conductors, 366.
——, irrigation duty of, and the principles on which its increase depends, 319.
Waterworks, on the laying of subaqueous mains of the Regensburg, across the Danube and the Regen, 322.
Wedding, H., Dr., on the treatment of argentiferous zinc in North America, 360.
Welch, E. F., admitted student, 105.
Wernich, H., on the length of Bessemer steel rails, 288.
Whitthread's process for the treatment of sewage, 119.
Whitty, I. J., elected associate, 104.
Wightman, W. F., elected member, 104.
Wilde, F. S., admitted student, 105.
Wilkes, S. R., admitted student, 251.
Williams, R. Price, remarks as to the repairs and renewals of locomotives, 35.—Ditto in dissent from Mr. McDonnell's conclusions in regard to the train mileage and traffic receipts of different railways, 35.—Ditto as to the items "repairs of tools" and "shop expenses," 36.—Ditto as to the money-life value of the Great Southern and Western engines, 37.—Table showing the maintenance and renewals of the engines of the Great Southern and Western rail-

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way for ten years, 38.—Ditto as to the average age of the engines, 39.—Ditto as to the ratio of cost of materials to labour, 39.
Willis, R. H., admitted student, 1.
Wilson, A. H., admitted student, 1.
———, J. W., jun., elected associate, 104.
Wingate, R., transferred member, 1.
Winkelmann, A., on the influence of temperature on the specific heat of mercury, 357.
Wiseman, W., elected associate, 104.
Wolters, J., on the manufacture of white forge pig iron from the oolitic iron ores of Luxemburg, 352.
Woods, E., his report on the consumption of fuel and the evaporation of water on the Liverpool and Manchester railway, referred to, 48.—Remarks as to the maintenance and renewals of locomotives, 60.—Ditto as to an experiment in working different sections of the London and North-Western railway with the same engines, in order to estimate the effect of gradients, 60.—Ditto as to the early engines on the Liverpool and Manchester railway, 61.
Wortham, A., admitted student, 1.
Wragge, E., "Canadian Narrow-gauge Railways," 252.
Wright, A. P., elected associate, 104.
Wyatt, J. W., admitted student, 105.

Young, S., elected associate, 104.

Zinc, on the treatment of argentiferous, in North America, 360.
Zürcher, J., improvement of the river Aar, between Thun and Uttigen, 302.

END OF VOL. XLVIII.

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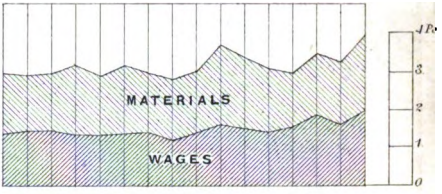

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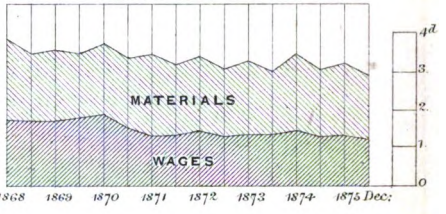

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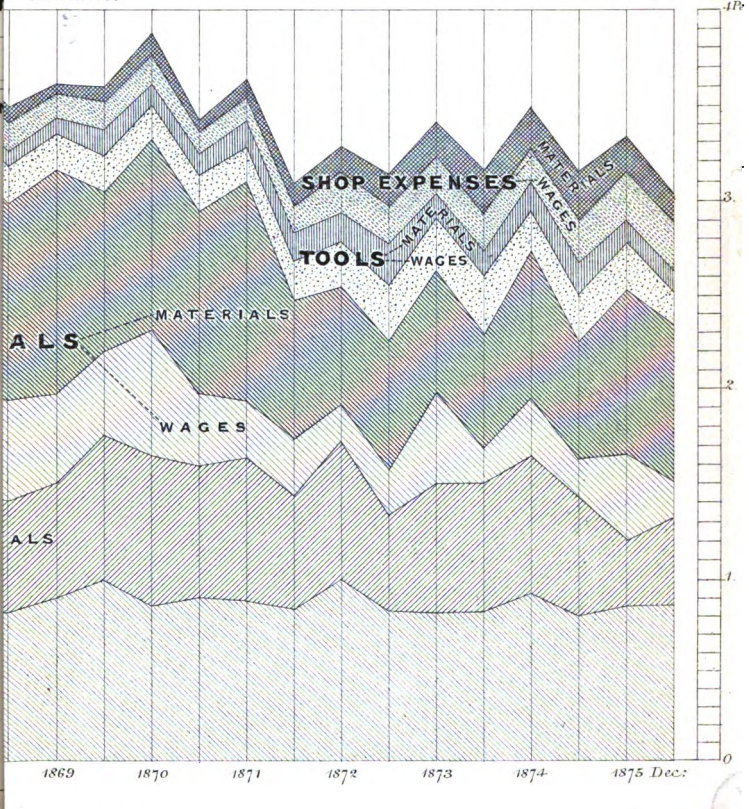

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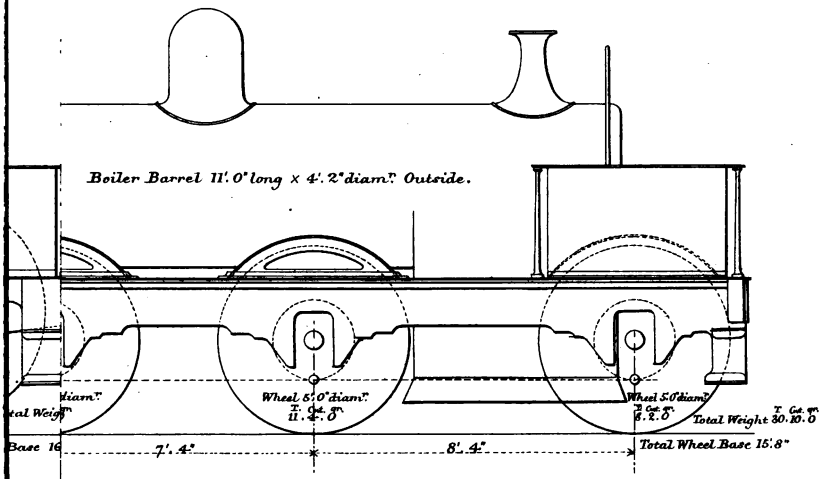

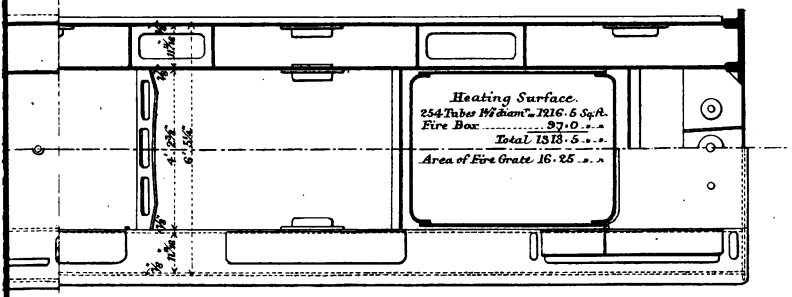

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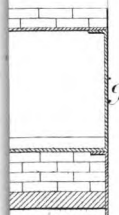

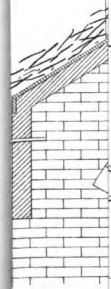

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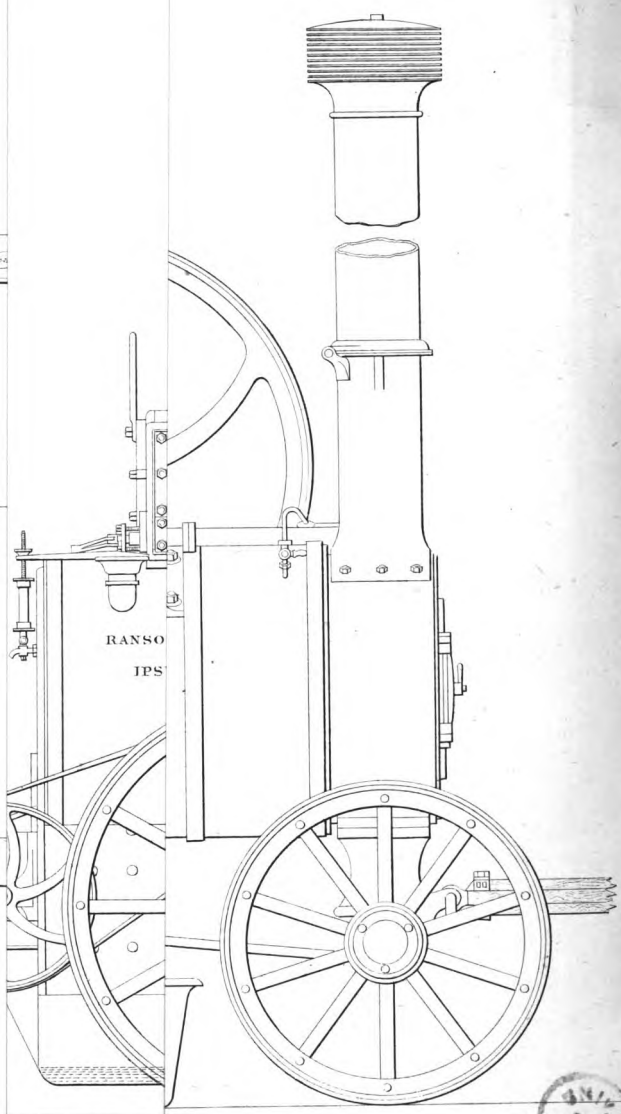

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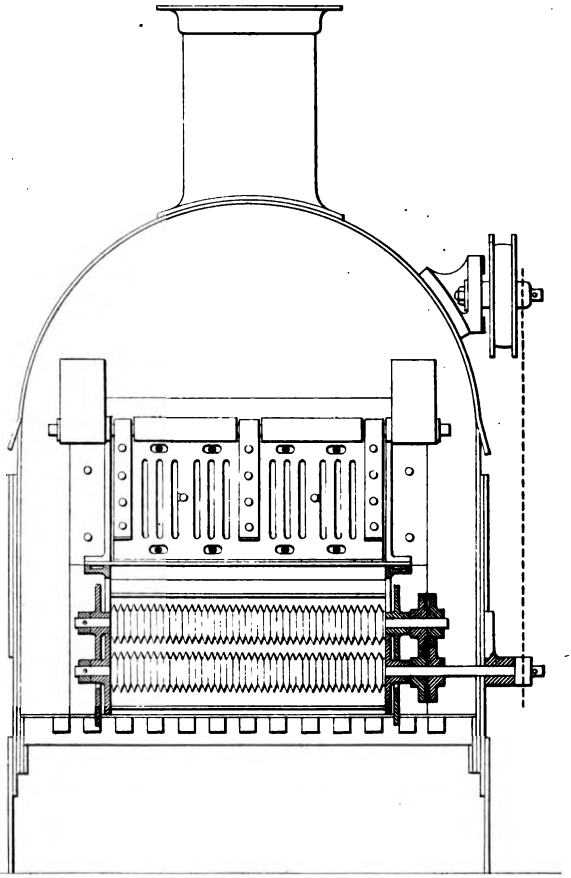

END VIEW OF FIREBOX, SHOWING ROLLERS,
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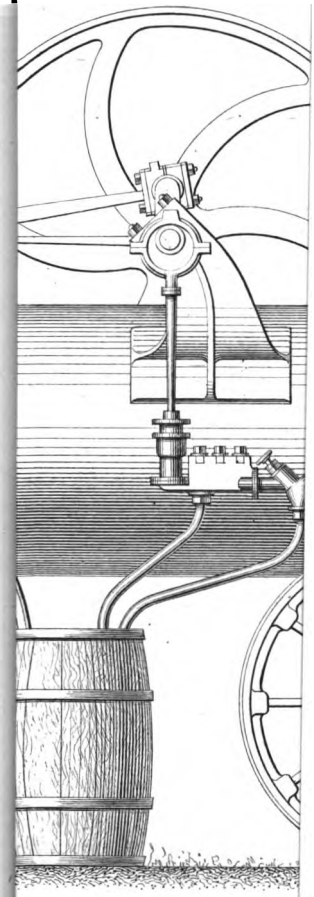

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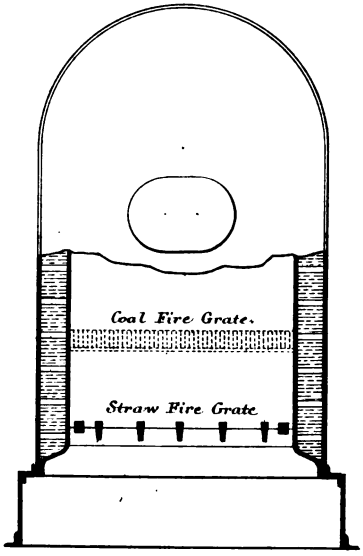

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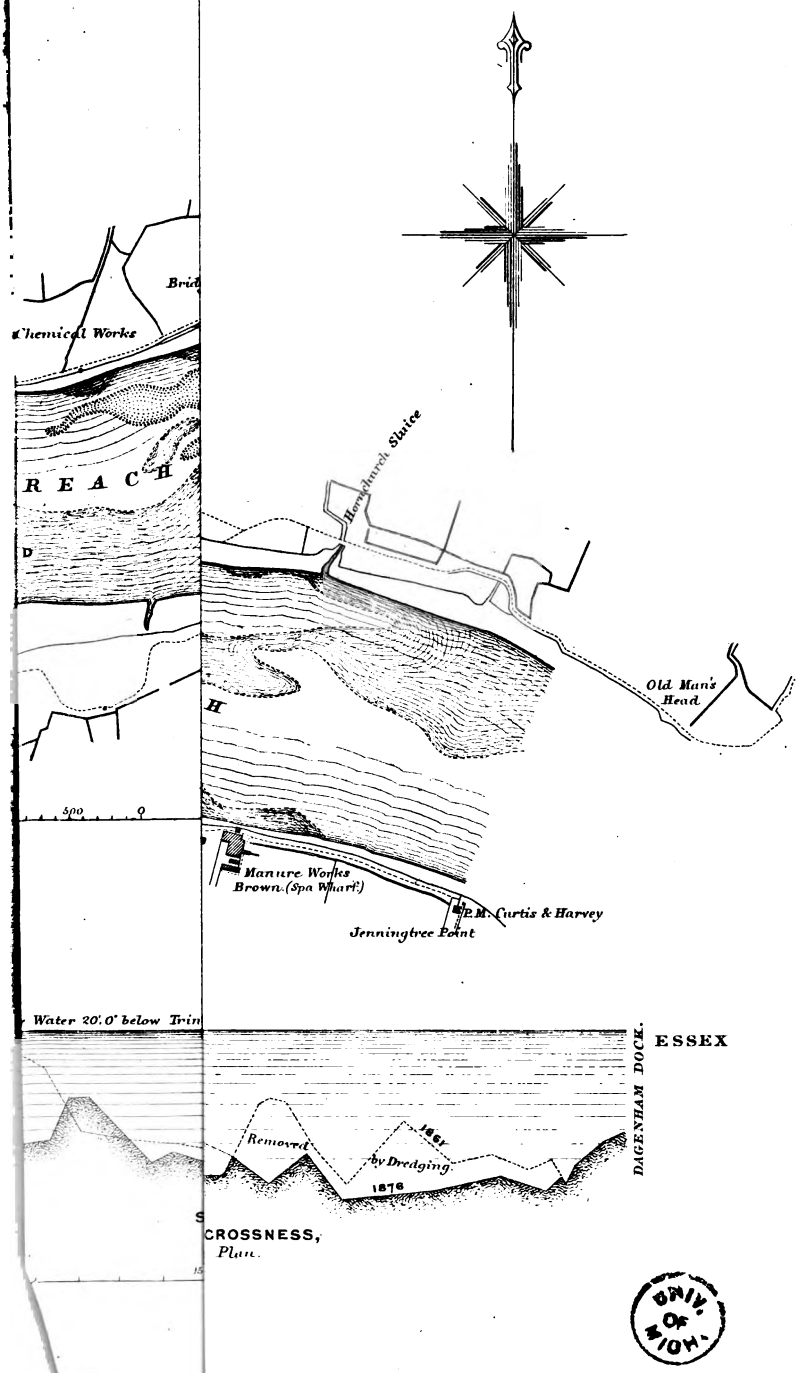

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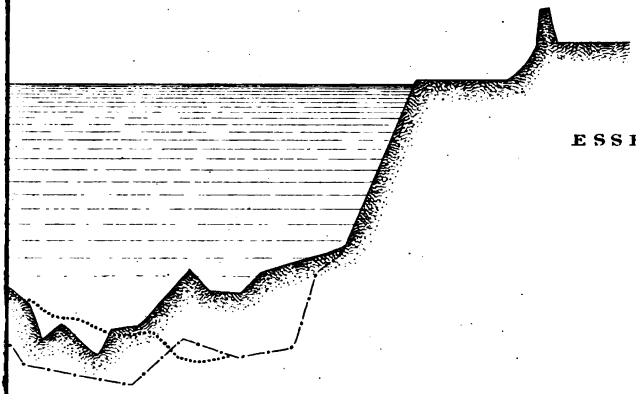

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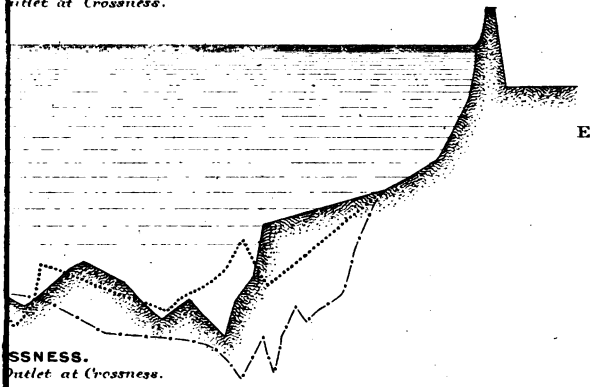

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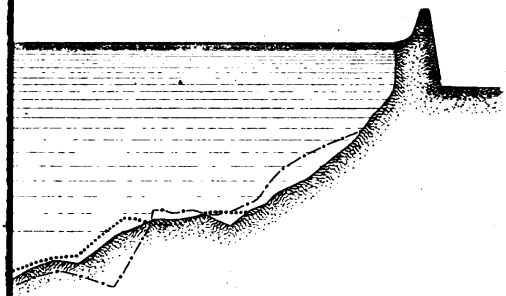

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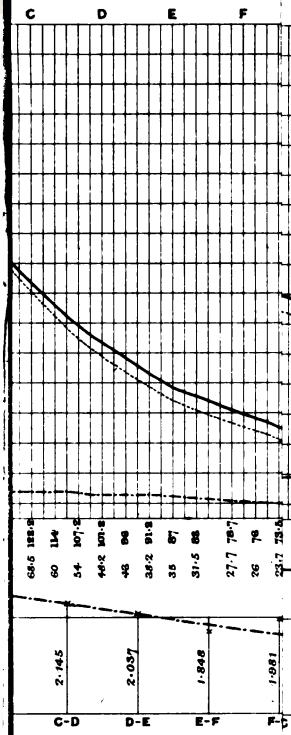

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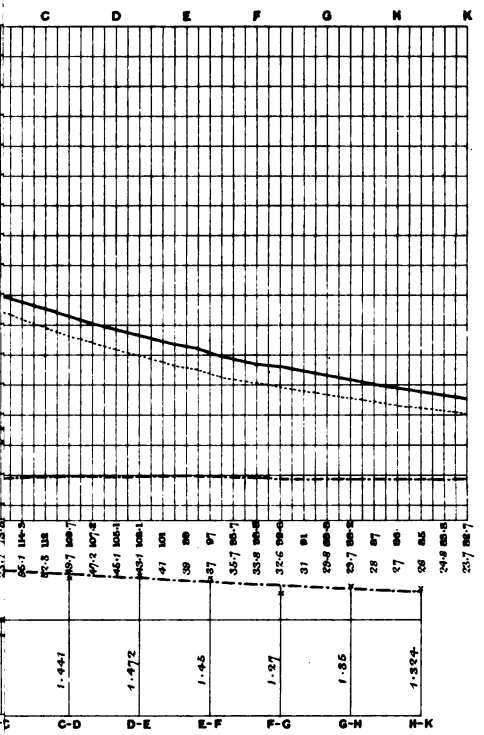

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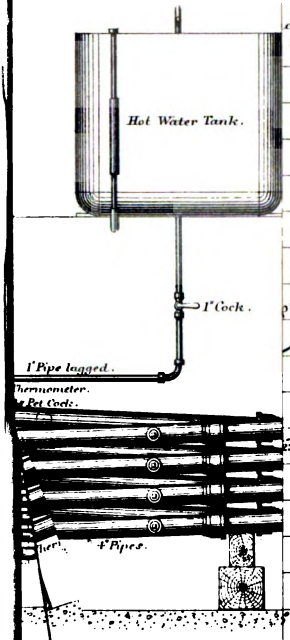

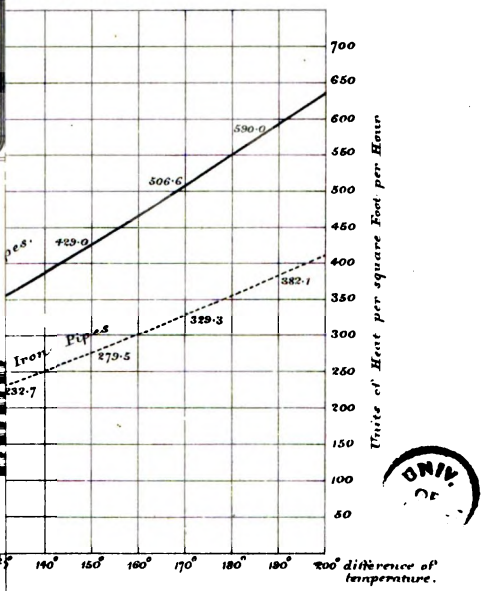

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